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A COMPUTER PROGRAM FOR . ᴌICOPTER ROTOR NOISE USING LOWSON'S FORMULA IN THE TIME DOMAIN

by

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JULY 22, 1975

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16. Abstract

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This report describes the digital computer program including the methods used in the calculations, a flow chart, program D3910 source listing, instructions for the user, and two test cases with input and output listings and output plots.

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CONTENTS

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SUMMARY

A computer program (D3910) has been developed to calculate both the far-field and near-field acoustic pressure signature of a tilted rotor in hover or uniform forward speed. The analysis, carried out in the time domain, is based on Lowson's formulation of the acoustic field of a moving force.

This report describes the digital computer program including the methods used in the calculations, a flow chart, program D3910 source listing, instructions for the user, and two test cases with input and output listings and output plots.

INTRODUCTION

When conditions of compactness of acoustic sources apply, the acoustic pressure signature of a rotor can be calculated by a fairly simple formula due to M. V. Lowson (ref. 1). Although Lowson's formula has usually been used in the frequency domain, it can be used to compute a time history of the acoustic pressure signature due to steady and periodic forces on the rotor.

This report describes a computer program developed to calculate both the far-field and near-field acoustic pressure signature of a tilted rotor in hover or uniform forward speed using Lowson's formula in the time domain. Results obtained from this program agree with those available which use frequency analysis. Apart from the inclusion of forward speed, one advantage appearing from this program is its speed and simplicity.

A description of the computer program for helicopter rotor noise is presented herein along with the methods used in the calculations, a flow chart, program listing, instructions for the user, and two test cases with input and output listings and output plots.

SYMBOLS

$\vec{A}$	a vector whose components (a_1, a_2, a_3) describe the location of the source point force on the rotor disk, meters (see fig. 1)
C	normalized amplitude of each harmonic obtained by the Fourier decomposition of the thrust
C'	phase angle of each harmonic obtained by the Fourier decomposition of the thrust, radians
$\vec{F}$	net force of the rotor blade on the air, Newtons
$\vec{M}$	velocity of the point force/speed of sound
M_r	mach number of point force relative to the observer's direction
N	number of harmonics of the load
P	sound pressure, Newtons/meter^2
r	distance between the source point force and the observer, meters (see fig. 1)
$\vec{\hat{r}}$	unit vector from the location of the source point force towards the observer
R	effective radius of the rotor disk inscribed by the net force on the blades, meters (see fig. 1)
RPM	velocity of the rotor, revolutions/min.
t	time the sound is observed, seconds

T thrust, Newtons

V_h velocity of the vehicle, meters/sec. (see fig. 1)

$\vec{X}$ a vector whose components (x_1, x_2, x_3) describe the position of the observer, meters (see fig. 1)

x_o initial x_1 component of the observer's position, meters

α ratio of the magnitude of the torque force to the thrust force

Φ angle made by the normal to the rotor disk and the horizontal direction, radians (see fig. 1)

Ω angular velocity of the rotor, radians/sec. (see fig. 1)

τ time the sound is generated, seconds

τ_o initial generation time, seconds

$\Delta\tau$ time increment

θ blade angle, radians (see fig. 1)

θ_o initial blade angle, radians

$\Delta\theta$ blade angle increment, radians

Subscripts and superscripts:

i denotes a computation for the ith source

j denotes a computation for the jth iteration

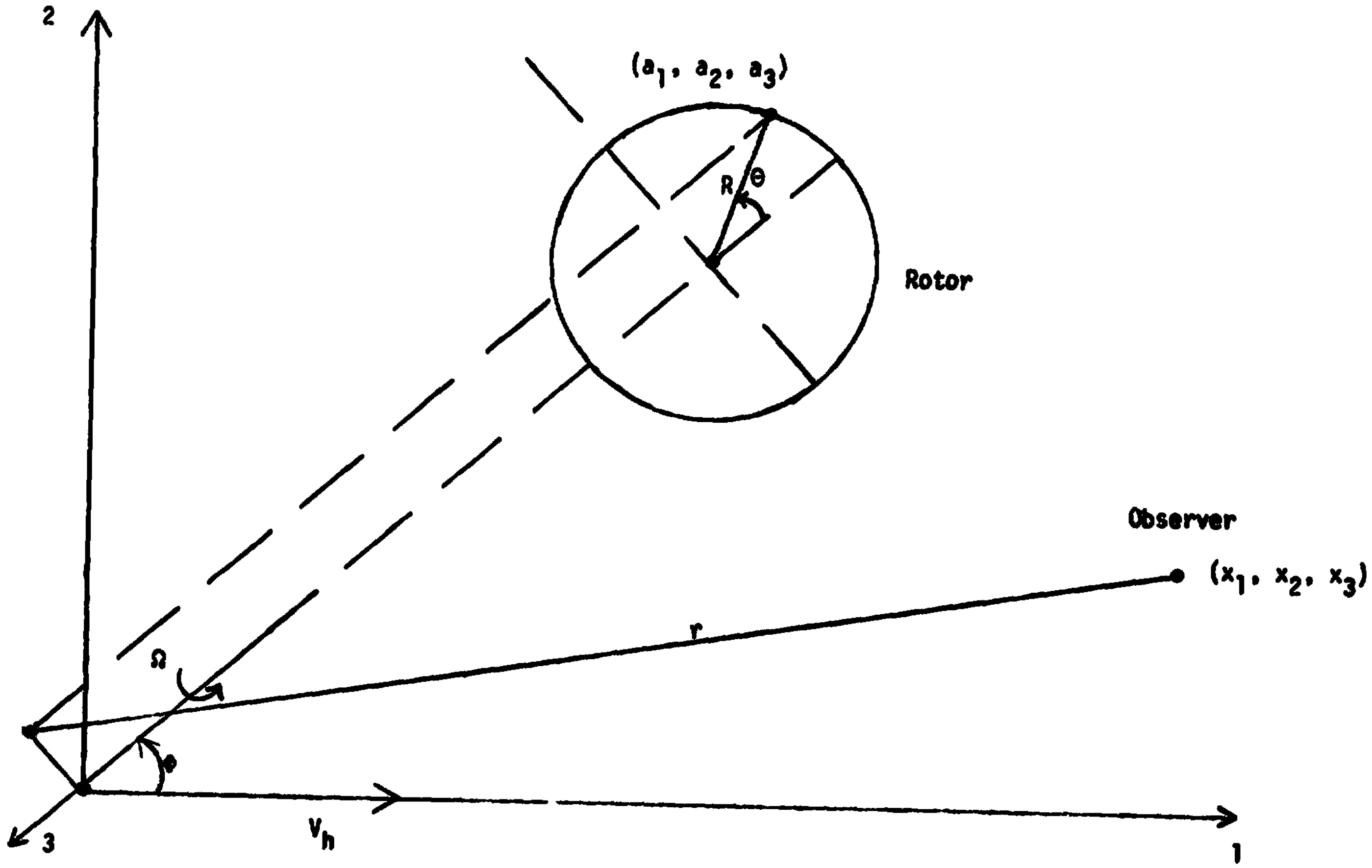


Figure 1. - Rotor Coordinate System

PROBLEM DESCRIPTION

To apply Lowson's formula in the time domain for multiple sound source systems, that is, multiple blades on a given rotor, each source is followed separately and its acoustic pressure signature is calculated as a function of time. The overall pressure at any given time is the sum of the pressures which reach the observer at that time from the individual sources. Since there is a lag between the time that the sound is generated and the time that the sound arrives at the observer, care must be taken in executing this procedure. To get meaningful results, the arrival times of the acoustic pressure signals from all sources must overlap.

In order to do this, the initial arrival time of the signal generated at the source nearest the observer must first be determined. Then each of the other sources is retraced back in time until its signal arrives within a specified range (determined by the number of harmonics and rotational velocity of the rotor) of the initial arrival time of the signal from the nearest source. This results in each source having its own initial generation time at which a signal is generated, and this signal arriving at the observer within a specified range of the initial arrival time of the signal from the nearest source. Thus, a time history of the acoustic pressure signature is computed for each source from its respective initial generation time. Then it is possible to sum the pressures from the individual sources to determine the overall pressure at any given arrival time.

This application of Lowson's formula is described in reference 2. The computation of the components of Lowson's formula is described by the following equations:

<u>Blade Angle Increment</u>

$$\text{if } N = 0, \quad \Delta\theta = 10\left(\frac{\pi}{180}\right) \tag{1}$$

$$\text{if } N > 0, \quad \Delta\theta = \left(\frac{10}{N}\right)\left(\frac{\pi}{180}\right)$$

Angular Velocity of the Rotor

$$\Omega = 6 \left(\frac{\pi}{180}\right) \left(\mathrm{RPM}\right) \tag{2}$$

Time Increment

$$\Delta\tau = \frac{\Delta\theta}{\Omega} \tag{3}$$

After determining the initial generation time, τ_o, and the initial blade angle, θ_o, for each source, compute for each iteration, j, and each source, i:

Blade Angle

$$\theta_i^j = \theta_{o_i} + (j - 1)\,\Delta\theta \tag{4}$$

Generation Time

$$\tau_i^j = \tau_{o_i} + (j - 1)\,\Delta\tau \tag{5}$$

Observer Position (x_1 component only)

$$x_{1_i}^j = x_o - V_h\,\tau_i^j \tag{6}$$

Source Location

$$\vec{A}_i^j = \begin{Bmatrix} -R \sin\theta_i^j \sin\Phi \\ R \sin\theta_i^j \cos\Phi \\ R \cos\theta_i^j \end{Bmatrix} \tag{7}$$

Distance Between Source and Observer

$$r_i^j = \sqrt{(x_{1_i}{}^j - a_{1_i}{}^j)^2 + (x_{2_i}{}^j - a_{2_i}{}^j)^2 + (x_{3_i}{}^j - a_{3_i}{}^j)^2} \tag{8}$$

Observation Time

$$t_i^j = \tau_i^j + \frac{r_i^j}{340.} \quad \text{(where 340 M/Sec. is the speed of sound)} \tag{9}$$

Velocity of Point Force/Speed of Sound

$$\vec{M}_i^j = \frac{1}{340} \begin{Bmatrix} V_h - R\Omega \cos \theta_i^j \sin \Phi \\ R\,\Omega \cos \theta_i^j \cos \Phi \\ R\,\Omega \sin \theta_i^j \end{Bmatrix} \tag{10}$$

Derivative

$$\left(\frac{\partial \vec{M}}{\partial \tau}\right)_i^j = \frac{1}{340} \begin{Bmatrix} R\,\Omega^2 \sin \theta_i^j \sin \Phi \\ -R\,\Omega^2 \sin \theta_i^j \cos \Phi \\ R\,\Omega^2 \cos \theta_i^j \end{Bmatrix} \tag{11}$$

Unit Vector From Source Towards Observer

$$\vec{\hat{r}}_i^j = \frac{1}{r_i^j} \left(\vec{X}_i^j - \vec{A}_i^j\right) \tag{12}$$

Mach Number

$$M_{r_i}{}^j = \vec{M}_i^j \cdot \vec{\hat{r}}_i^j \quad \text{(where } \cdot \text{ denotes dot product)} \tag{13}$$

<u>Thrust</u>

$$T_i^j = C_1 + \sum_{K=2}^{N+1} C_k \cos \; (k\,\theta_i^j + C_k') \tag{14}$$

<u>Derivative</u>

$$\left(\frac{\partial T}{\partial \tau}\right)_i^j = - \sum_{k=2}^{N+1} k\, C_k\, \Omega \sin\, (k\,\theta_i^j + C_k') \tag{15}$$

<u>Net Force of Rotor Blade</u>

$$\vec{F}_i^j = \left\{ \begin{array}{l} -T_i^j\,(\cos\Phi + \alpha \cos\theta_i^j \sin\Phi) \\ \\ T_i^j\,(-\sin\Phi + \alpha\cos\theta_i^j \cos\Phi) \\ \\ \alpha\, T_i^j\, \sin\theta_i^j \end{array} \right\} \tag{16}$$

<u>Derivative</u>

$$\left(\frac{\partial \vec{F}}{\partial \tau}\right)_i^j = \left\{ \begin{array}{l} -\left(\frac{\partial T}{\partial \tau}\right)_i^j (\cos\Phi \text{ [illegible] } \sin\Phi) + \text{ [illegible] } \sin\Phi \\ \\ \left(\frac{\partial T}{\partial \tau}\right)_i^j (-\sin\Phi + \alpha\cos\theta_i^j\cos\Phi) - \alpha\,\Omega\, T_i^j \sin\theta_i^j \cos\Phi \\ \\ \alpha\,(\Omega\, T_i^j \cos\theta_i^j + \left(\frac{\partial T}{\partial \tau}\right)_i^j \sin\theta_i^j) \end{array} \right\} \tag{17}$$

<u>Sound Pressure</u> (Lowson's formula)

$$p_i^j = \frac{1}{4\pi\, r_i^j\, (1 - M_{r_i}^j)^2} \left[\frac{1}{340} \left\{ \hat{\vec{r}}_i^{\,j} \cdot \left(\frac{\partial \vec{F}}{\partial \tau}\right)_i^j \right\} + \frac{\hat{\vec{r}}_i^{\,j} \cdot \vec{F}_i^j}{340\,(1 - M_{r_i}^{\,j})}\, \hat{\vec{r}}_i^{\,j} \cdot \left(\frac{\partial \vec{M}}{\partial \tau}\right)_i^j + \frac{(1 - \vec{M}_i^j \cdot \vec{M}_i^j)\, \vec{F}_i^j \cdot \hat{\vec{r}}_i^{\,j}}{r_i^j\,(1 - M_{r_i}^{\,j})} - \frac{\vec{F}_i^j \cdot \vec{M}_i^j}{r_i^j} \right] \quad (18)$$

Due to irregular arrival times of the signals, the stored values for each source must be interpolated at specified observer times and then summed to obtain the overall pressure signature. This is accomplished by using a second-order Lagrangian interpolation method.

The calculations are continued for a specified number of iterations as explained in the Input Description.

PROGRAM DESCRIPTION

The program D3910 is written in FORTRAN IV under the specifications of the Langley Research Center's SCOPE operating system for the Control Data 6000 series. A FORTRAN variable list is given first, followed by a flow chart and a source listing.

This program reads the input and determines the blade nearest the observer by calculating the minimum initial arrival time of the sound pressure signal. Each of the other blades is then rotated back in time until the initial arrival time of its signal is within a certain range of the minimum initial arrival time. Next, a time history of the sound pressure generated by each blade is calculated, starting with the respective initial arrival time of each blade. To determine the total sound pressure generated, the sound pressure for each blade is interpolated at specific time points using a second-order Lagrangian interpolation method. These interpolated values are then summed, giving the total sound pressure for the specific points. The program then writes the time history of the total sound pressure, and if the user so chooses, the program plots the time history of the total sound pressure.

The interpolation subroutine, IUNI, and the plot subroutines, PSEUDO, CALPLT, AXES, LINE, and NFRAME, are called from the Langley subroutine library. Descriptions of these subroutines are included in the appendix, but the program listings for these subroutines are not included in this report.

FORTRAN Variable List

A	vector $\vec{A}$, the location of the source point force on the rotor disc, in meters
ALPHA	α, the ratio of the magnitude of the torque force to the thrust force
BETA	β, a constant used to determine the number of sets of total sound pressure to be computed (50 points per set)
CGAMMA	$\cos \gamma$
COEFF1	C, the normalized amplitude of each harmonic obtained by the Fourier decomposition of the thrust
COEFF2	C', the phase angle of each harmonic obtained by the Fourier decomposition of the thrust, in degrees
CPHI	$\cos \Phi$
CSAV	$\cos (i\theta + C_i'), i = 2, 3, . . ., N, N+1$
CTHETA	$\cos \theta$
DELTAU	$\Delta\tau$, time increment, in seconds
DELTET	$\Delta\theta$, blade angle increment, in degrees
DIST	r, the distance between the source point force and the observer, in meters
DF	$\frac{\partial \vec{F}}{\partial \tau}$ in Newtons/second

DM	$\frac{\partial \vec{M}}{\partial \tau}$
DOPFAC	$\frac{1}{1 - \vec{M} \cdot \vec{\hat{r}}}$
DTETR	$\Delta\theta$, blade angle increment, in radians
DTH	$\frac{dT}{d\tau}$
DUM1 } DUM2 }	Dummy variables used in calling subroutine LINE
EMR	$\vec{M} \cdot \vec{\hat{r}}$, mach number of the source point force relative to the observer's direction
EMSQ	$\vec{M} \cdot \vec{M}$
F	vector $\vec{F}$, the net force of the rotor blade on the air, in Newtons
FM	$\vec{F} \cdot \vec{M}$
GAMMA	initial blade angle for each blade, in radians
I	an index
IDENT	8 alphanumeric words of identifying information
IERR	an error code word returned from subroutine IUNI
IPLOT	an option to designate whether to plot
IPOWER	used in determining the plotting scale factors for the X and Y axes

IPT	an initializing indicator used in calling subroutine IUNI
IX IY	used in determining the plotting scale factors for the X and Y axes
J	used to count the number of points computed per blade
JPOWER	used in determining the minimum values for the X and Y axes
K	the number of sets of total sound pressure to be computed (50 points per set)
KC KJ KN	used to count the number of points computed per blade
KOUNT	an array containing the number of points computed for each blade
L M	indices
N	the number of harmonics of the load
N1	N + 1
NBLADE	the number of blades on the rotor
NL NP	indices
NPTS	the number of points to be plotted
NS	used to save the last 5 points for the next interpolation set
OMEGAD	Ω, angular velocity of the rotor, in degrees/second

OMEGAR	Ω, in radians/second
P	sound pressure, in Newtons/meter^2
PHI	Φ, the angle made by the normal to the rotor disk and the horizontal direction, in degrees
PHIR	Φ, in radians
PMAX	the maximum interpolated value of total sound pressure, in Newtons/meter^2
PMIN	the minimum interpolated value of total sound pressure, in Newtons/meter^2
POFT	the interpolated value of sound pressure returned from subroutine IUNI, in Newtons/meter^2
PTAB	a table used to store values of sound pressure for interpolation and for plotting
RADIUS	R, the effective radius of the rotor disk inscribed by the net force on the blades, in meters
RHAT	$\vec{\hat{r}}$, a unit vector from the location of the source point force towards the observer
RHDF	$\vec{\hat{r}} \cdot \frac{\partial \vec{F}}{\partial \tau}$
RHDM	$\vec{\hat{r}} \cdot \frac{\partial \vec{M}}{\partial \tau}$
RHF	$\vec{\hat{r}} \cdot \vec{F}$
ROC	$\frac{R\Omega}{340.}$ in radians

ROSC	$\frac{R\Omega^2}{340}$ in radians^2/sec
RPM	velocity of the rotor, in rev/min
SAVE	$i\theta + C_i'$, $i = 2, 3, \ldots, N, N+1$
SECTOR	$\frac{2\pi}{\text{NBLADE}}$ in radians
SGAMMA	$\sin \gamma$
SPHI	$\sin \Phi$
SSAV	$\sin (i\theta + C_i')$, $i = 2, 3, \ldots, N, N+1$
STHETA	$\sin \theta$
SUM1	$\cos \Phi + \alpha \cos \theta \sin \Phi$
SUM2	$-\sin \Phi + \alpha \cos \theta \cos \Phi$
SUM3	$\alpha\, \Omega\, T \sin \theta$
T	t, time the sound is observed, in seconds
TAU	τ, time the sound is generated, in seconds
TEST	initial τ for each blade, in seconds
TH	t, thrust, in Newtons
THETA	θ, blade angle, in radians
TIME	time at which the sound pressure is interpolated, in seconds

TMAJ distance between major tic marks on the plotting axes, in inches

TMAX used as maximum time for computing sound pressure and as maximum interpolation time, in seconds

TMIN initial arrival time of the sound produced by the blade nearest the observer, in seconds

TMIR number of divisions per inch for minor tic marks on the plotting axes

TO initial interpolation time point for each interpolation set, in seconds

TOTAL an array of the summed interpolated values for all blades at specific time points

TTAB a table used to store values of arrival time for interpolation and for plotting, in seconds

VH V_h, velocity of vehicle, in meters/second

VECM $\vec{M}$, velocity of the point force/speed of sound

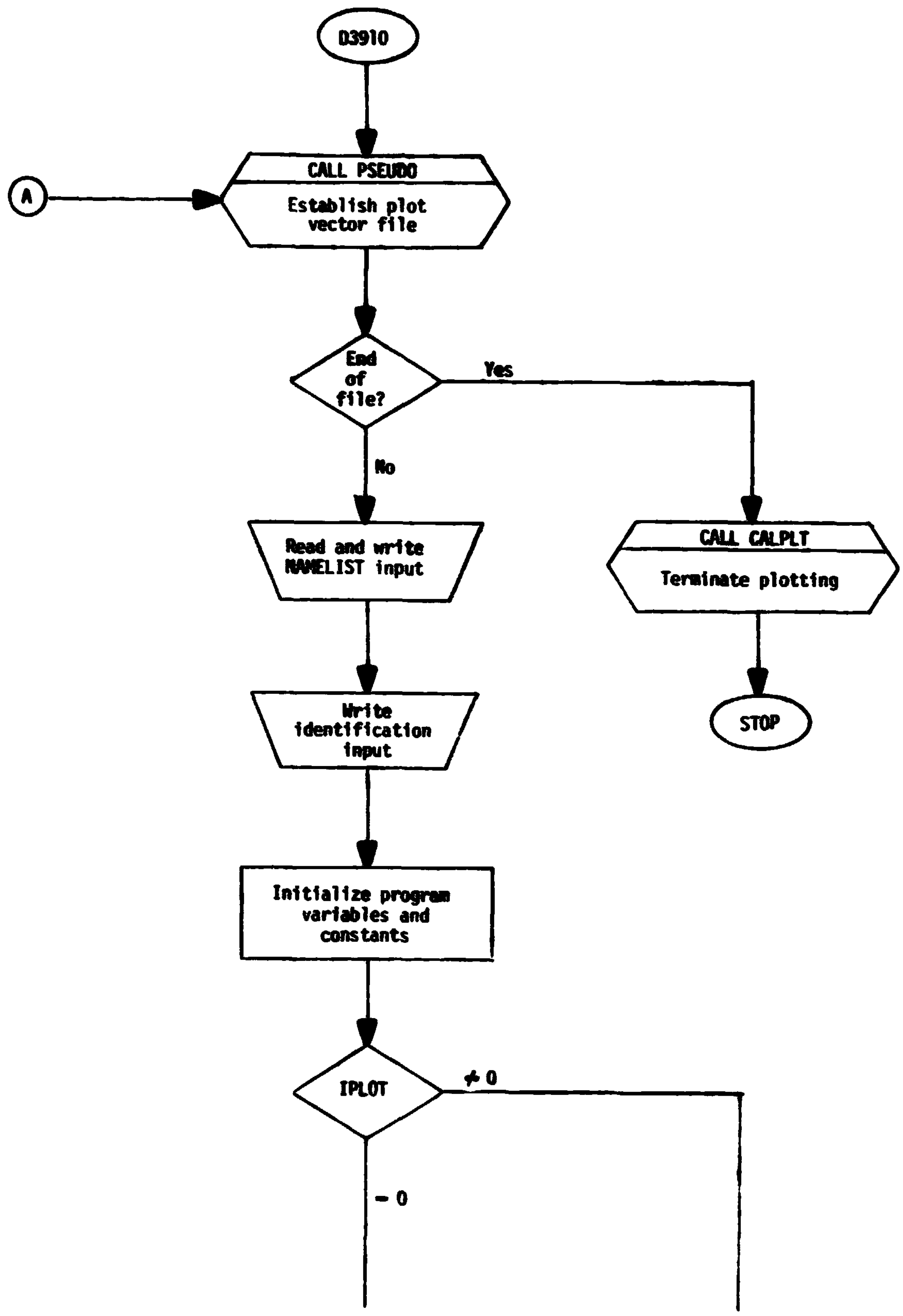
VHC $\frac{V_h}{340.}$

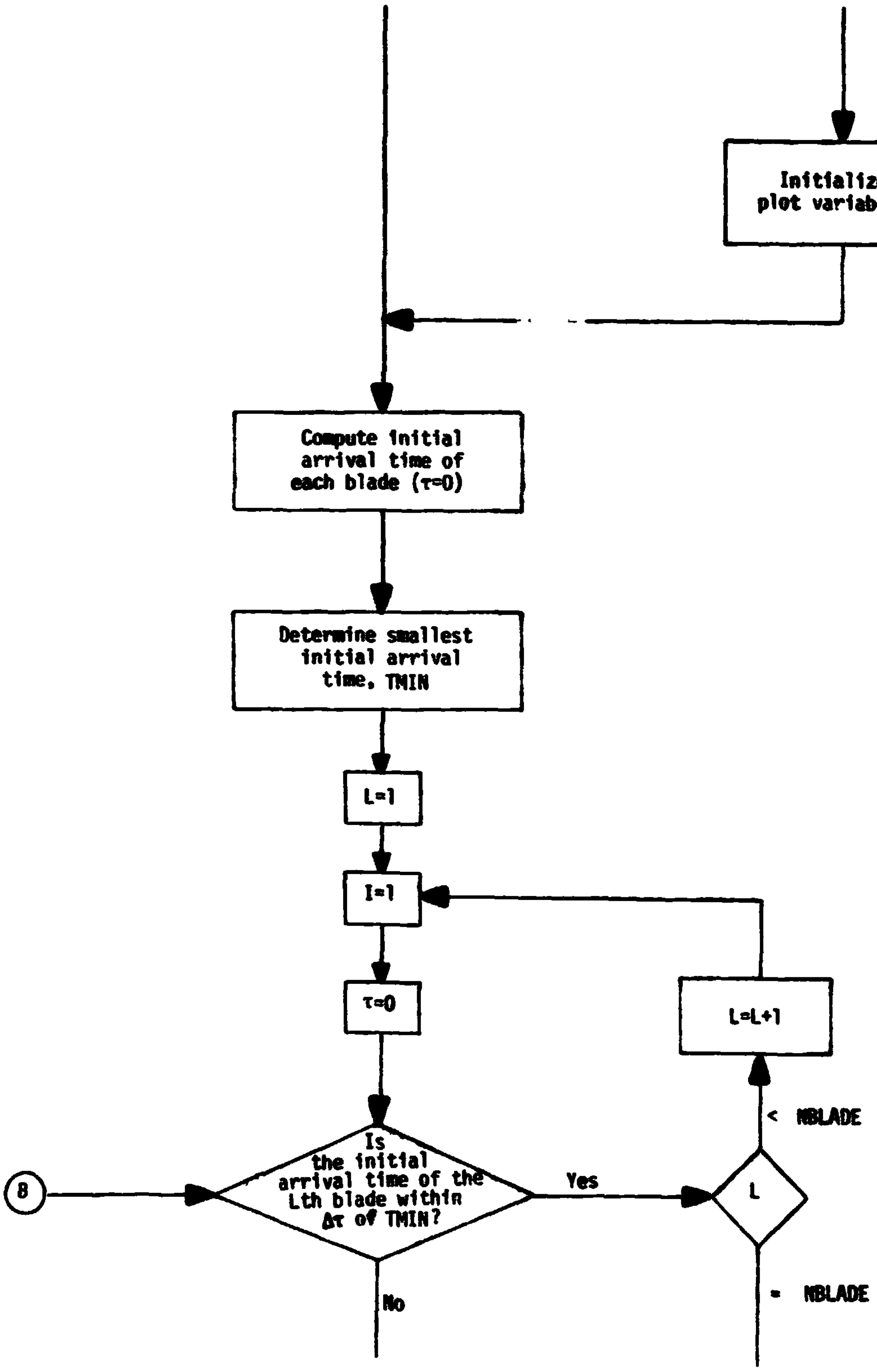
X x_1, x_2, x_3, the position of the observer at any given time τ, in meters

XO x_o, the initial x_1 component, in meters

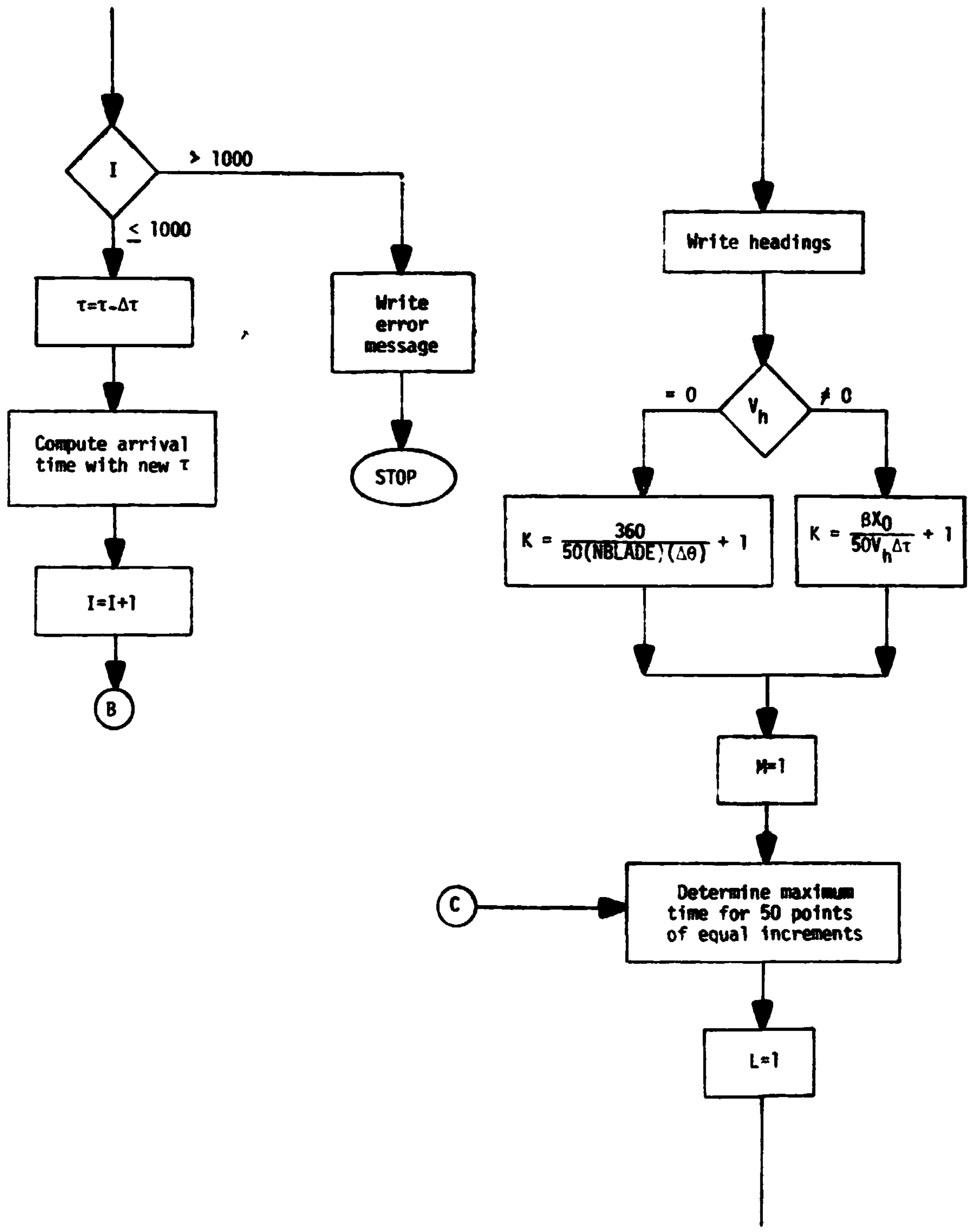
XSF scale factor for the X axis

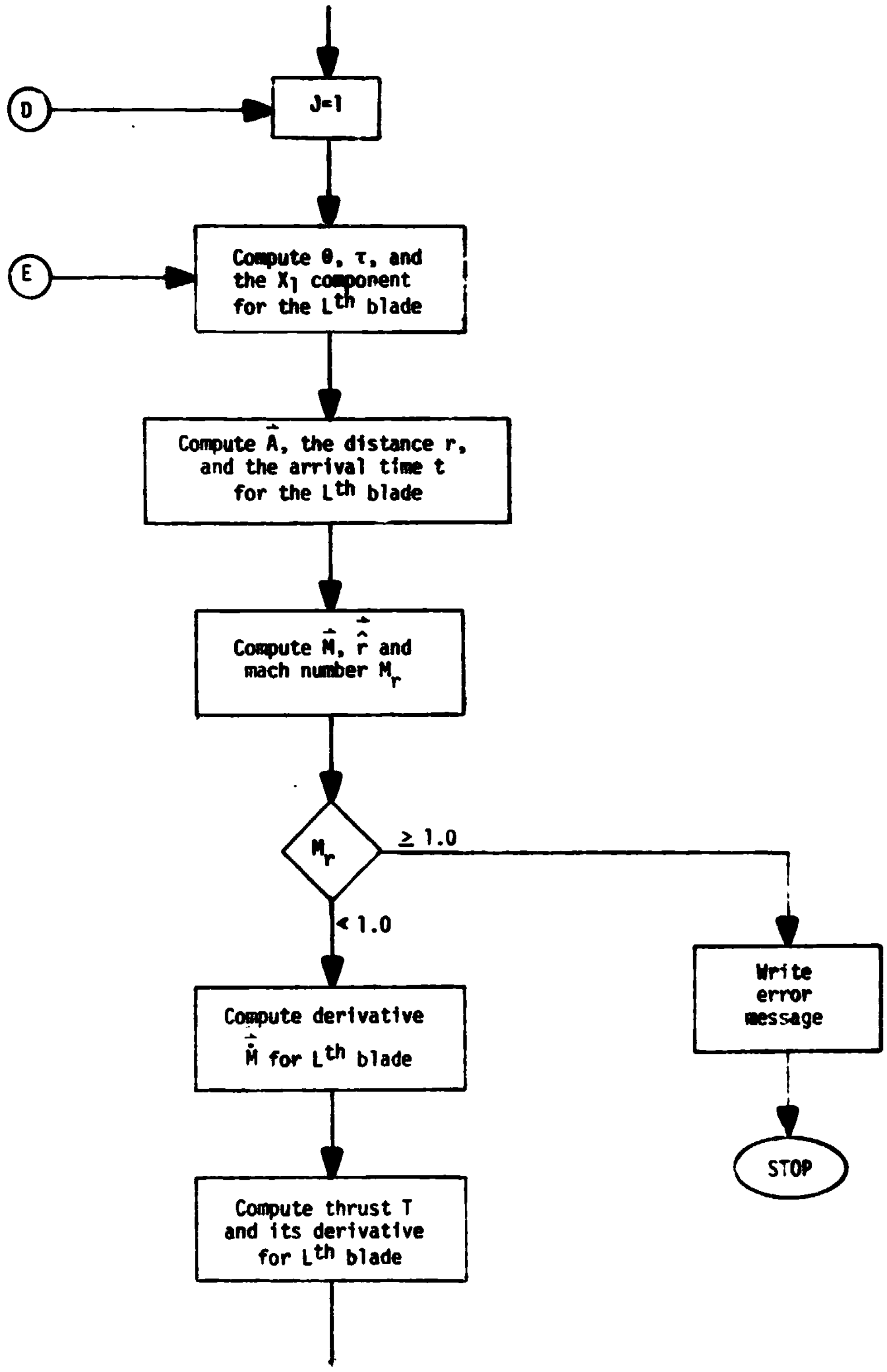
YSF scale factor for the Y axis

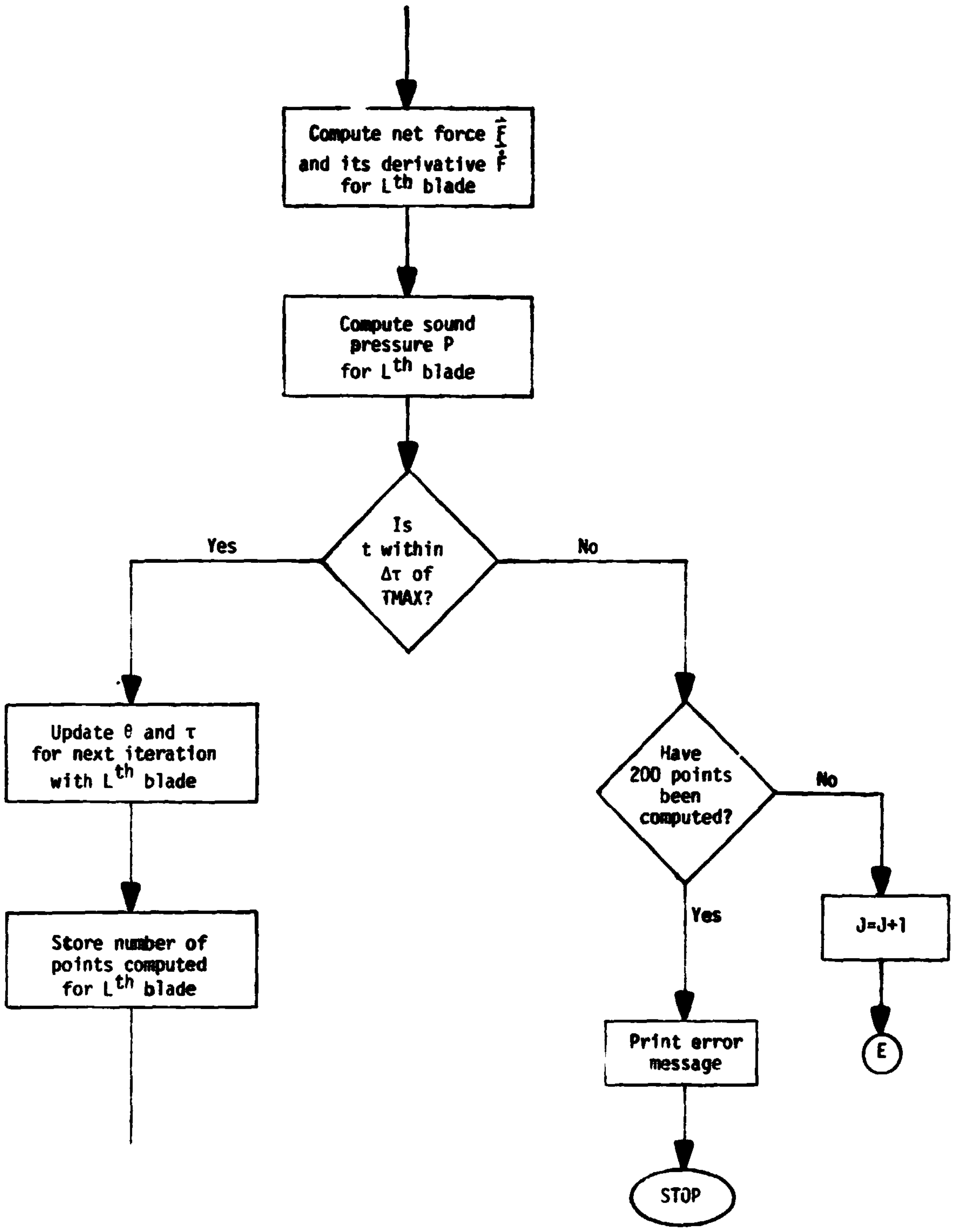

D3910
A
CALL PSEUDO
Establish plot vector file
End of file?
Yes
No
CALL CALPLT
Terminate plotting
STOP
Read and write NAMELIST input
Write identification input
Initialize program variables and constants
IPLOT
≠ 0
= 0

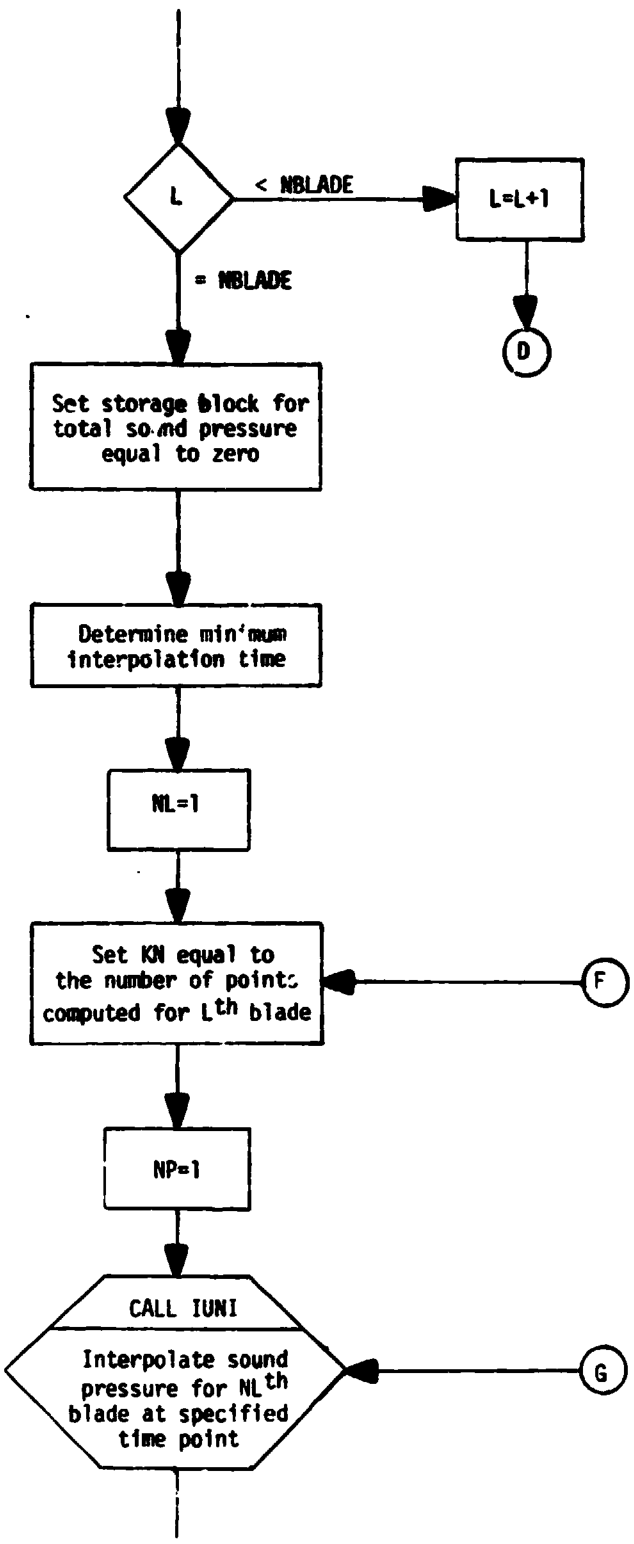


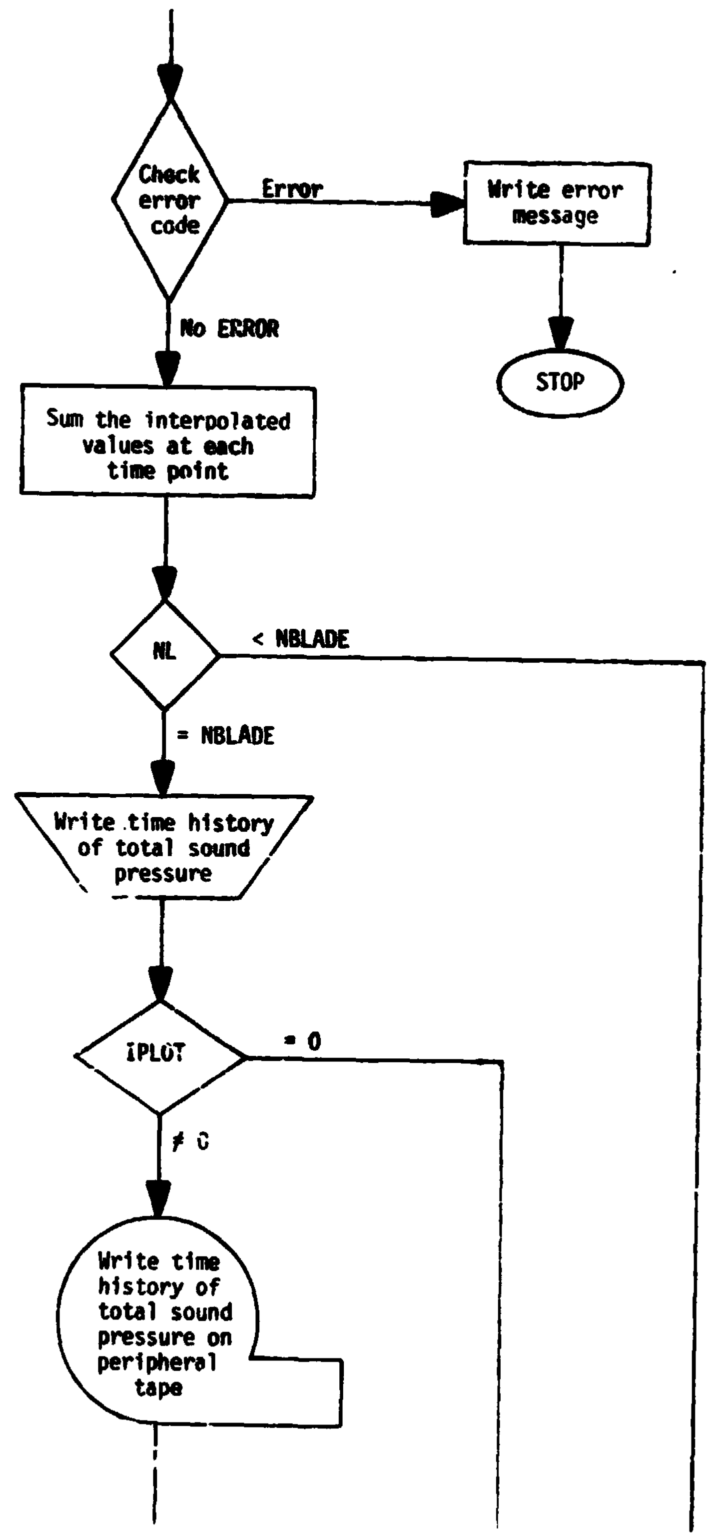
Initialize plot variables
Compute initial arrival time of each blade (τ=0)
Determine smallest initial arrival time, TMIN
L=1
I=1
τ=0
L=L+1
< NBLADE
B
Is the initial arrival time of the Lth blade within Δτ of TMIN?
Yes
L
No
= NBLADE

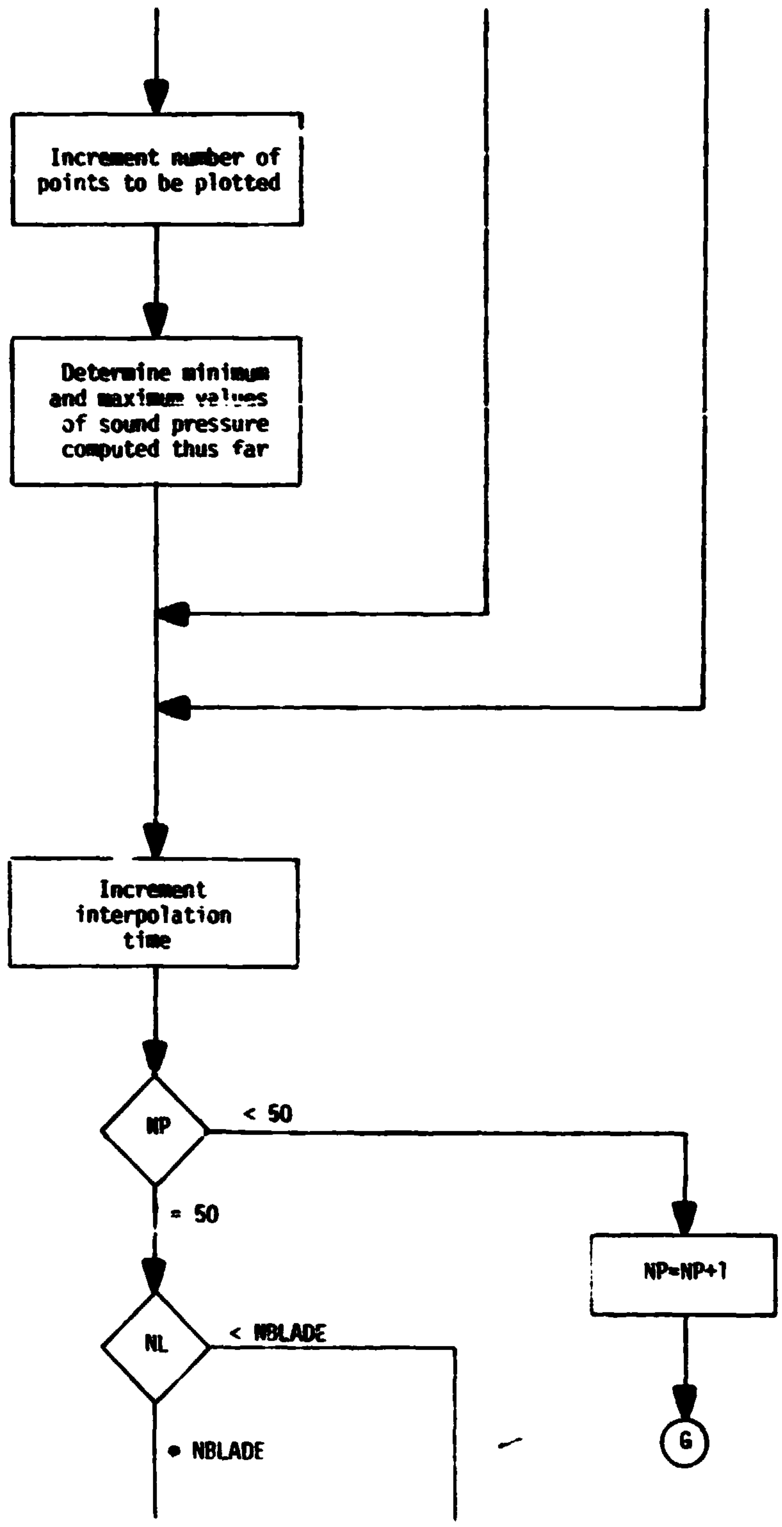

I
> 1000
≤ 1000
τ=τ-Δτ
Write error message
STOP
Compute arrival time with new τ
I=I+1
B
Write headings
V_h
= 0
≠ 0
$K = \frac{360}{50(\mathrm{NBLADE})(\Delta\theta)} + 1$
$K = \frac{\beta X_0}{50 V_h \Delta\tau} + 1$
M=1
C
Determine maximum time for 50 points of equal increments
L=1


D
E
J=1
Compute θ, τ, and the X1 component for the Lth blade
Compute A, the distance r, and the arrival time t for the Lth blade
Compute M, r̂ and mach number Mr
Mr
≥ 1.0
< 1.0
Write error message
STOP
Compute derivative Ṁ for Lth blade
Compute thrust T and its derivative for Lth blade

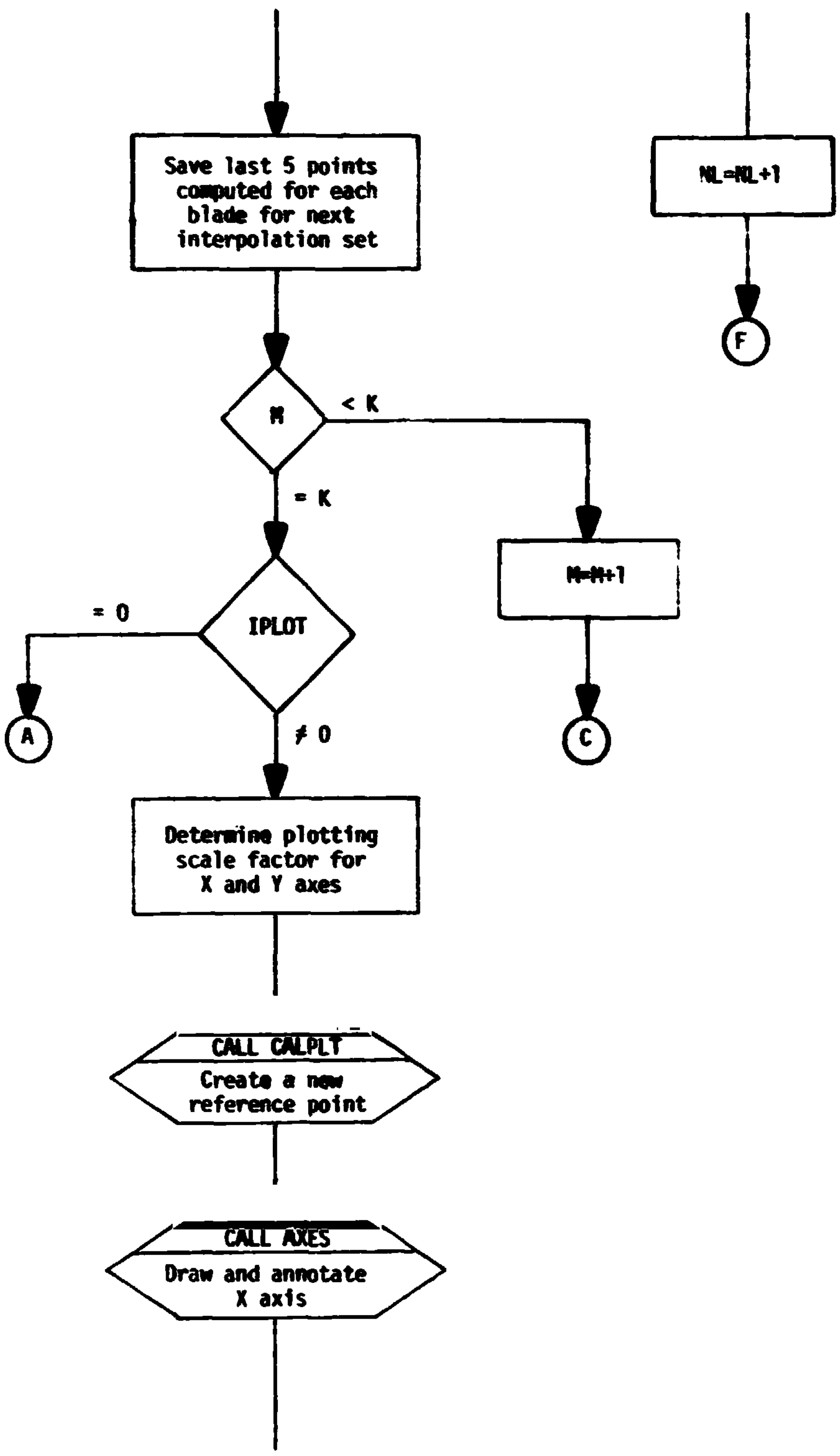

Compute net force $\vec{F}$ and its derivative $\dot{\vec{F}}$ for L^{th} blade
Compute sound pressure P for L^{th} blade
Is t within $\Delta\tau$ of TMAX?
Yes
No
Update θ and τ for next iteration with L^{th} blade
Store number of points computed for L^{th} blade
Have 200 points been computed?
No
Yes
J=J+1
E
Print error message
STOP

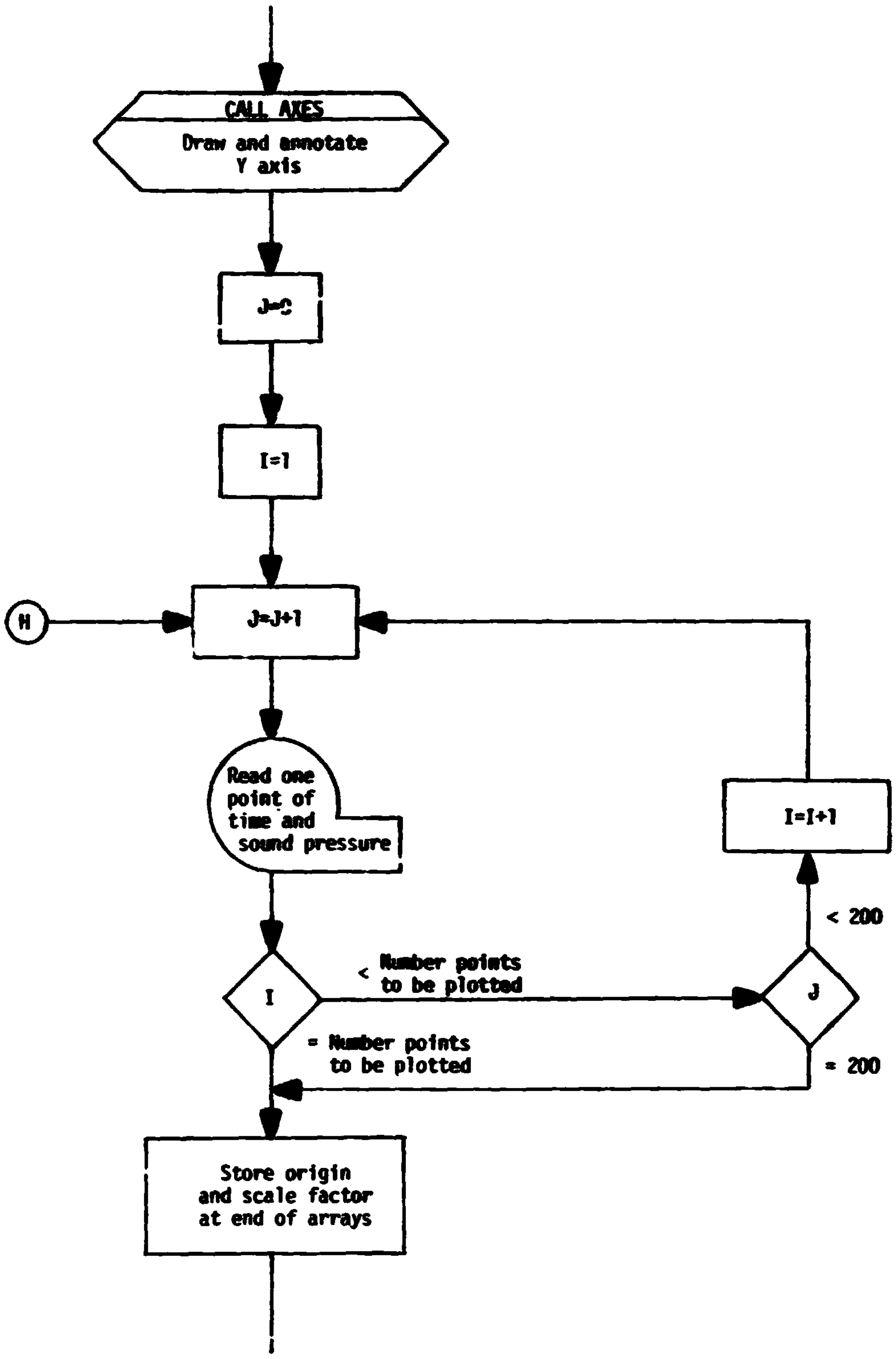

L
< NBLADE
L=L+1
D
= NBLADE
Set storage block for total sound pressure equal to zero
Determine minimum interpolation time
NL=1
Set KN equal to the number of points computed for Lth blade
F
NP=1
CALL IUNI
Interpolate sound pressure for NLth blade at specified time point
G

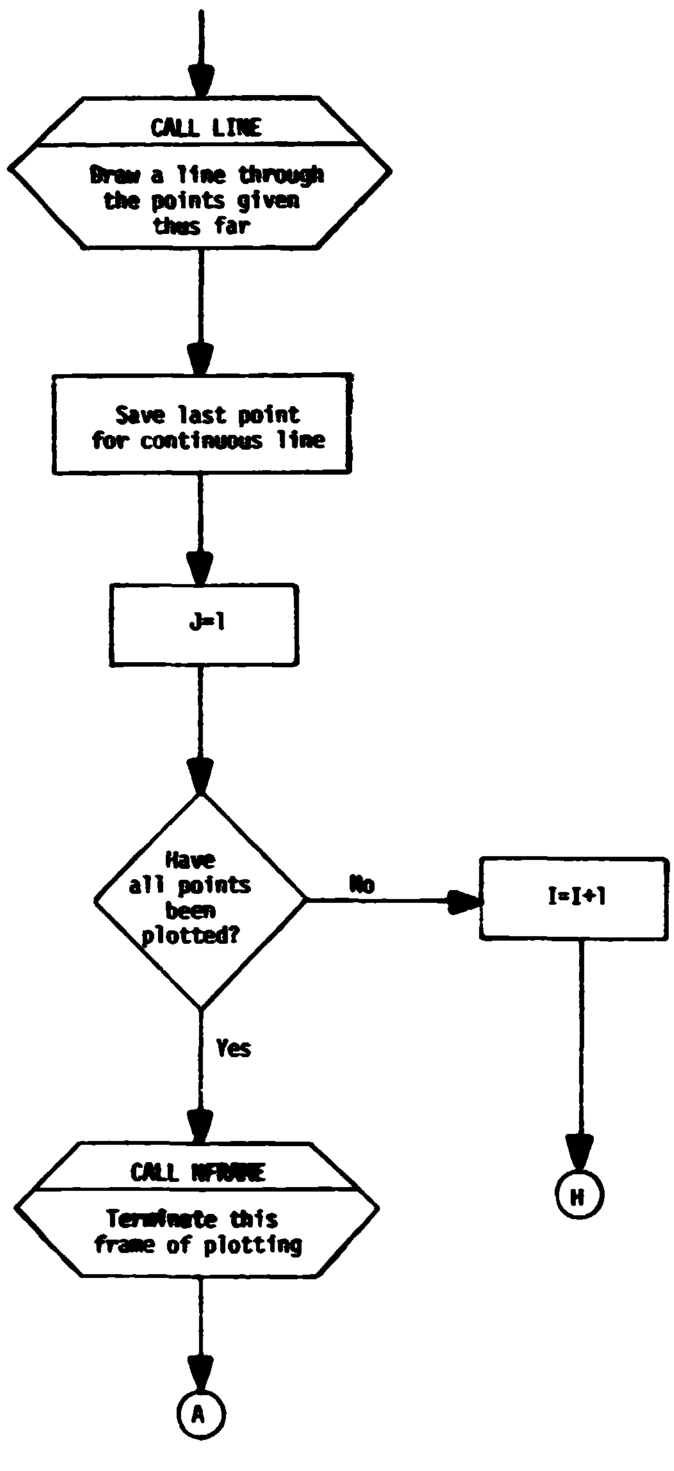

Check error code
Error
Write error message
STOP
No ERROR
Sum the interpolated values at each time point
NL
< NBLADE
= NBLADE
Write time history of total sound pressure
IPLOT
= 0
≠ 0
Write time history of total sound pressure on peripheral tape



Increment number of points to be plotted
Determine minimum and maximum values of sound pressure computed thus far
Increment interpolation time
NP
< 50
= 50
NP=NP+1
G
NL
< NBLADE
= NBLADE


Save last 5 points computed for each blade for next interpolation set
M
< K
= K
M=M+1
C
IPLOT
= 0
A
≠ 0
Determine plotting scale factor for X and Y axes
CALL CALPLT
Create a new reference point
CALL AXES
Draw and annotate X axis
NL=NL+1
F


CALL AXES
Draw and annotate Y axis
J=0
I=1
H
J=J+1
Read one point of time and sound pressure
I=I+1
< 200
< Number points to be plotted
I
J
= Number points to be plotted
= 200
Store origin and scale factor at end of arrays


CALL LINE
Draw a line through the points given thus far
Save last point for continuous line
J=1
Have all points been plotted?
No
I=I+1
Yes
CALL NFRAME
Terminate this frame of plotting
A
H

```
      PROGRAM ROTOR (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, TAPE10)
C
      DIMENSION A(3), COEFF1(50), COEFF2(50), DF(3), DM(3), F(3),
     1GAMMA(4), IDENT(8), KOUNT(4), P(200,4), PTAB(202,1), RHAT(3),
     2T(200,4), TEST(4), TOTAL(200), TTAB(202), VECM(3), X(3)
C
C
      NAMELIST /DATA/ ALPHA, BETA, COEFF1, COEFF2, IPLOT, N, NBLADE,
     1PHI, RADIUS, RPM, VH, X
C
C     *** INPUT ***
C                   (COEFF2 MUST BE GIVEN IN DEGREES. THESE ARE THE PHASE
C                   ANGLES OF EACH HARMONIC STARTING FROM FUNDAMENTAL.
C                   SET THE PHASE OF FUNDAMENTAL TO 0.0)
C
      CALL PSEUDO
  500 READ (5,501) IDENT
  501 FORMAT (8A10)
      IF (EOF,5) 502,503
  502 IF (IPLOT.EQ.1) CALL CALPLT(0.,0.,999)                          PLOT
      STOP
  503 READ (5,DATA)
      WRITE(6,DATA)
      PRINT 504, IDENT
  504 FORMAT(1H1,2X,8A10///)
C
C     *** INITIALIZATION ***
C
      X0 = X(1)
      EN = N
      IF(N.EQ.0) EN=1.
      DELTET = 10. / EN
      N1 = N+1
      OMEGAD = RPM * 6.
      DELTAU = DELTET / OMEGAD
      DTETR = DELTET * .0174532925
      OMEGAR = OMEGAD * .0174532925
      PHIR = PHI * .0174532925
      CPHI = COS(PHIR)
      SPHI = SIN(PHIR)
      DO 10 I=1,N1
   10 COEFF2(I) = COEFF2(I) * .0174532925
      VHC = VH / 340.
      ROC = (RADIUS * OMEGAR) / 340.
      ROSC = ROC * OMEGAR
      SECTOR = 6.283185306 / NBLADE
      IF (IPLOT.EQ.0) GO TO 40
      PMIN = 1.E10                                                     PLOT
      PMAX = 1.E-10                                                    PLOT
      NPTS = 0                                                         PLOT
      REWIND 10                                                        PLOT
C
C     *** DETERMINE INITIAL TIME POINT FOR INTERPOLATION ***
C
   40 DO 50 L=1,NBLADE
      GAMMA(L) = (L-1) * SECTOR
      CGAMMA = COS(GAMMA(L))
      SGAMMA = SIN(GAMMA(L))
      A(1) = -RADIUS * SGAMMA * SPHI
      A(2) = RADIUS * SGAMMA * CPHI
      A(3) = -RADIUS * CGAMMA
      DIST = ((X0-A(1))**2 + (X(2)-A(2))**2 + (X(3)-A(3))**2)**.5
      TEST(L) = DIST/340.
   50 CONTINUE
      TMIN = 1.E10
```

```
      DO 51 L=1,NBLADE
   51 IF (TEST(L).LT.TMIN) TMIN=TEST(L)
C
C     *** ADJUST TAU FOR EACH BLADE ***
C
      DO 75 L=1,NBLADE
      I=1
      TAU = 0.
      GAMMA(L) = (L-1) * SECTOR
   60 IF((TEST(L)-TMIN).LE.DELTAU) GO TO 74
      IF(I.LE.1000) GO TO 70
      PRINT 505,L
  505 FORMAT(1H1,*TIME HAS NOT REACHED TMIN FOR BLADE*I2)
      STOP
   70 TAU = TAU - DELTAU
      X(1) = XO - VH * TAU
      GAMMA(L) = GAMMA(L) - DTETR
      CGAMMA = COS(GAMMA(L))
      SGAMMA = SIN(GAMMA(L))
      A(1) = -RADIUS * SGAMMA * SPHI
      A(2) = RADIUS * SGAMMA * CPHI
      A(3) = -RADIUS * CGAMMA
      DIST = ((X(1)-A(1))**2 + (X(2)-A(2))**2 + (X(3)-A(3))**2) **.5
      TEST(L) = TAU + DIST/340.
      I=I+1
      GO TO 60
   74 TEST(L) = TAU
   75 CONTINUE
C
C     *** K IS THE NUMBER OF SETS OF INTERPOLATIONS ***
C
      PRINT 507
  507 FORMAT(///7X,*TIME*15X,*INTERPOLATED PRESSURE SUM*)
      KC = 0
      IF (VH.EQ.0.0) GO TO 100
      K = IFIX(BETA*XO / (VH*DELTAU*50)) + 1
      GO TO 101
  100 K = IFIX (360 / (NBLADE * DELTET * 50)) + 1
  101 DO 1002 M = 1,K
      TMAX = TMIN + (49+(M-1)*50)*DELTAU
C
C     *** NBLADE IS THE NUMBER OF BLADES ***
C
      DO 109 L=1,NBLADE
      J = 1
C
C     *** BLADE ANGLE, RELATIVE TIME, AND X(1) COMPONENT OF OBSERVER ***
C
  105 THETA = GAMMA(L) + (J-1) * DTETR
      CTHETA = COS(THETA)
      STHETA = SIN(THETA)
      TAU = TEST(L) + (J-1) * DELTAU
      X(1) = XO - VH * TAU
C
C     *** A-VECTOR, DISTANCE, AND ABSOLUTE TIME ***
C
      A(1) = -RADIUS * STHETA * SPHI
      A(2) = RADIUS * STHETA * CPHI
      A(3) = -RADIUS * CTHETA
      DIST = ((X(1)-A(1))**2 + (X(2)-A(2))**2 + (X(3)-A(3))**2) **.5
      KJ = KC + J
      T(KJ,L) = TAU + DIST / 340.
C
C     *** M-VECTOR, RHAT-VECTOR, AND THEIR DOT PRODUCT ***
C
```

```
      VECM(1) = VH/340. - ROC * CTHETA * SPHI
      VECM(2) = RCC * CTHETA * CPHI
      VECM(3) = RUC * STHETA
      EMSQ   = VECM(1)*VECM(1) + VECM(2)*VECM(2) + VECM(3)*VECM(3)
C
      RHAT(1) = (X(1) - A(1)) / DIST
      RHAT(2) = (X(2) - A(2)) / DIST
      RHAT(3) = (X(3) - A(3)) / DIST
C
      EMR = VECM(1)*RHAT(1) + VECM(2)*RHAT(2) + VECM(3)*RHAT(3)
      IF (EMR.LT.1.0) GO TO 103
      PRINT 102
  102 FORMAT (* MACH NUMBER IS NOT LESS THAN ONE. PROGRAM ABORTED.*)
      STOP
C
C     *** PARTIAL DERIVATIVE OF M WITH RESPECT TO TAU ***
C
  103 DM(1) = ROSC * STHETA * SPHI
      DM(2) = -ROSC * STHETA * CPHI
      DM(3) = ROSC * CTHETA
C
C     *** THRUST AND ITS DERIVATIVE ***
C
      TH = COEFF1(1)
      DTH = 0.
      IF (N.EQ.0) GO TO 110
      DO 104 I=2,N1
      SAVE = I * THETA + COEFF2(I)
      SSAV = SIN(SAVE)
      CSAV = COS(SAVE)
      TH = TH + COEFF1(I) * CSAV
  104 DTH = DTH - I * COEFF1(I) * SSAV * OMEGAR
C
C     *** F-VECTOR ***
C
  110 SUM1 = CPHI + ALPHA*CTHETA*SPHI
      SUM2 = -SPHI + ALPHA*CTHETA*CPHI
      F(1) = -TH * SUM1
      F(2) = TH * SUM2
      F(3) = ALPHA * TH * STHETA
      FM = F(1)*VECM(1) + F(2)*VECM(2) + F(3)*VECM(3)
C
C     *** PARTIAL DERIVATIVE OF F WITH RESPECT TO TAU ***
C
      SUM3 = ALPHA * OMEGAR * TH * STHETA
      DF(1) = -DTH * SUM1 + SUM3 * SPHI
      DF(2) = DTH * SUM2 - SUM3 * CPHI
      DF(3) = ALPHA * OMEGAR * TH * CTHETA + ALPHA * DTH * STHETA
C
C     *** SOUND PRESSURE ***
C
      RHDF = RHAT(1)* DF(1) + RHAT(2)*DF(2) + RHAT(3)*DF(3)
      DOPFAC = 1./(1.-EMR)
      RHF = (RHAT(1)*F(1) + RHAT(2)*F(2) + RHAT(3)*F(3)) * DOPFAC
      RHDM = RHAT(1)*DM(1) + RHAT(2)*DM(2) + RHAT(3)*DM(3)
      P(KJ,L) = .0795774716 * (DOPFAC**2/DIST) * (RHDF/340. + RHF*RHDM
     1/340. + ((1.-EMSQ) * RHF - FM) / DIST)
      IF ((TMAX - T(J,L)) .LE. DELTAU) GO TO 108
      IF(KJ.GE.200) GO TO 106
      J=J+1
      GO TO 105
  106 PRINT 107,L,M
  107 FORMAT (1H1,*BLADE *I1,* FAILED TO REACH TMAX IN 200 ITERATIONS FO
     1R INTERPOLATION SET*,I3)
      STOP
```

```
  108 GAMMA(L) = THETA + DTETR
      TEST(L) = TAU + DELTAU
      KOUNT(L) = KJ
  109 CONTINUE
C
C     *** INTERPOLATION ***
C
      DO 204 NP=1,50
  204 TOTAL(NP) = 0.
      TO    = TMIN + (M-1)*50*DELTAU
      DO 220 NL=1,NBLADE
      TIME = TO
      KN = KOUNT(NL)
      DO 206 NP=1,KN
      TTAB(NP) = T(NP,NL)
  206 PTAB(NP,1) = P(NP,NL)
      IPT = -1
      DO 220 NP=1,50
  207 CALL IUNI(200,KOUNT(NL),TTAB,1,PTAB,2,TIME,POFT,IPT,IERR)
C
C     *** CHECK ERROR CODE ***
C
      IF(IERR.EQ.0) GO TO 213
      IF(IERR.LT.0) GO TO 209
      PRINT 208, IERR
  208 FORMAT (1H0,I5,*TH ELEMENT OUT OF ORDER. NO INTERPOLATION.*)
      STOP
  209 IERR = IABS(IERR)
      GO TO (210,211,212,213),IERR
  210 PRINT 214
  214 FORMAT (1H0,*IORDER = 0*)
      STOP
  211 PRINT 215
  215 FORMAT (1H0,*ONE ELEMENT IN X ARRAY*)
      STOP
  212 PRINT 216
  216 FORMAT (1H0,*INSUFFICIENT NUMBER OF POINTS. NO INTERPOLATION.*)
      STOP
  213 TOTAL(NP) = TOTAL(NP) + POFT
      IF(NL.LT.NBLADE) GO TO 217
      PRINT 508, TIME, TOTAL(NP)
  508 FORMAT(2X,E15.7,14X,E15.7)
      IF (IPLOT.EQ.0) GO TO 217
      WRITE (10) TIME,TOTAL(NP)                                         PLOT
      NPTS = NPTS + 1                                                   PLOT
      IF(TOTAL(NP).LT.PMIN) PMIN=TOTAL(NP)                              PLOT
      IF(TOTAL(NP).GT.PMAX) PMAX=TOTAL(NP)                              PLOT
  217 TIME = TIME + DELTAU
  220 CONTINUE
C
C     *** SAVE LAST 5 POINTS FOR NEXT SET OF TABLES ***
C
  230 DO 250 NL=1,NBLADE
      NS = KOUNT(NL) -5
      DO 250 NP=1,5
      T(NP,NL) = T(NP+NS,NL)
  250 P(NP,NL) = P(NP+NS,NL)
      KC = 5
C
 1002 CONTINUE
      IF (IPLOT.EQ.0) GO TO 500
C                                                                       PLOT
C     *** PLOT TIME VS. SOUND PRESSURE ***                              PLOT
C                                                                       PLOT
      TMAX = TIME - DELTAU                                              PLOT
```

```
      END FILE 10                                                       PLOT
      REWIND 10                                                         PLOT
C                                                                       PLOT
C     *** DETERMINE SCALE FACTORS ***                                   PLOT
C                                                                       PLOT
      XSF = (TMAX-TMIN)/22.                                             PLOT
      IPOWER = 0                                                        PLOT
 1005 IF(XSF.GT..999999999) GO TO 1006                                  PLOT
      XSF = XSF*10.                                                     PLOT
      IPOWER = IPOWER + 1                                               PLOT
      GO TO 1005                                                        PLOT
 1006 IX = IFIX(XSF+.5)                                                 PLOT
      XSF = FLOAT(IX)/10.**IPOWER                                       PLOT
      JPOWER = 0                                                        PLOT
 1065 IF (JPOWER.GE.IPOWER) GO TO 1066                                  PLOT
      TMIN = TMIN*10.                                                   PLOT
      JPOWER = JPOWER + 1                                               PLOT
      GO TO 1065                                                        PLOT
 1066 IX = IFIX(TMIN)                                                   PLOT
      TMIN = FLOAT(IX)/10**JPOWER                                       PLOT
C                                                                       PLOT
      YSF = (PMAX-PMIN)/9.                                              PLOT
      IPOWER = 0                                                        PLOT
 1007 IF(YSF.GT..99999999) GO TO 1008                                   PLOT
      YSF = YSF * 10                                                    PLOT
      IPOWER = IPOWER + 1                                               PLOT
      GO TO 1007                                                        PLOT
 1008 IY = IFIX(YSF+.5)                                                 PLOT
      YSF = FLOAT(IY)/10.**IPOWER                                       PLOT
      JPOWER = 0                                                        PLOT
 1085 IF(JPOWER.GE.IPOWER) GO TO 1086                                   PLOT
      PMIN = PMIN*10.                                                   PLOT
      JPOWER = JPOWER + 1                                               PLOT
      GO TO 1085                                                        PLOT
 1086 IY = IFIX(PMIN-.5)                                                PLOT
      PMIN = FLOAT(IY)/10**JPOWER                                       PLOT
C                                                                       PLOT
C     *** DRAW AXES ***                                                 PLOT
C                                                                       PLOT
      TMAJ = 1.                                                         PLOT
      TMIR = 10.                                                        PLOT
      CALL CALPLT(1.,1.,-3)                                             PLOT
      CALL AXES (0.,0.,0.0,25.,TMIN,XSF,TMAJ,TMIR,4HTIME,    .2,-4)     PLOT
      CALL AXES (0.,0.,90.,10.,PMIN,YSF,TMAJ,TMIR,8HPRESSURE,.2,8)      PLOT
C                                                                       PLOT
C     *** READ AND PLOT POINTS ***                                      PLOT
C                                                                       PLOT
      J = 0                                                             PLOT
      DO 2005 I=1,NPTS                                                  PLOT
      J = J + 1                                                         PLOT
      READ (10) TTAB(J), PTAB(J)                                        PLOT
      IF(I.GE.NPTS) GO TO 2000                                          PLOT
      IF(J.LT.200) GO TO 2005                                           PLOT
 2000 TTAB(J+1) = TMIN                                                  PLOT
      PTAB(J+1) = PMIN                                                  PLOT
      TTAB(J+2) = XSF                                                   PLOT
      PTAB(J+2) = YSF                                                   PLOT
      CALL LINE(TTAB,PTAB,J,1,0,DUM1,DUM2)                              PLOT
      TTAB(1) = TTAB(J)                                                 PLOT
      PTAB(1) = PTAB(J)                                                 PLOT
      J = 1                                                             PLOT
 2005 CONTINUE                                                          PLOT
      CALL NFRAME                                                       PLOT
      GO TO 500
      END
```

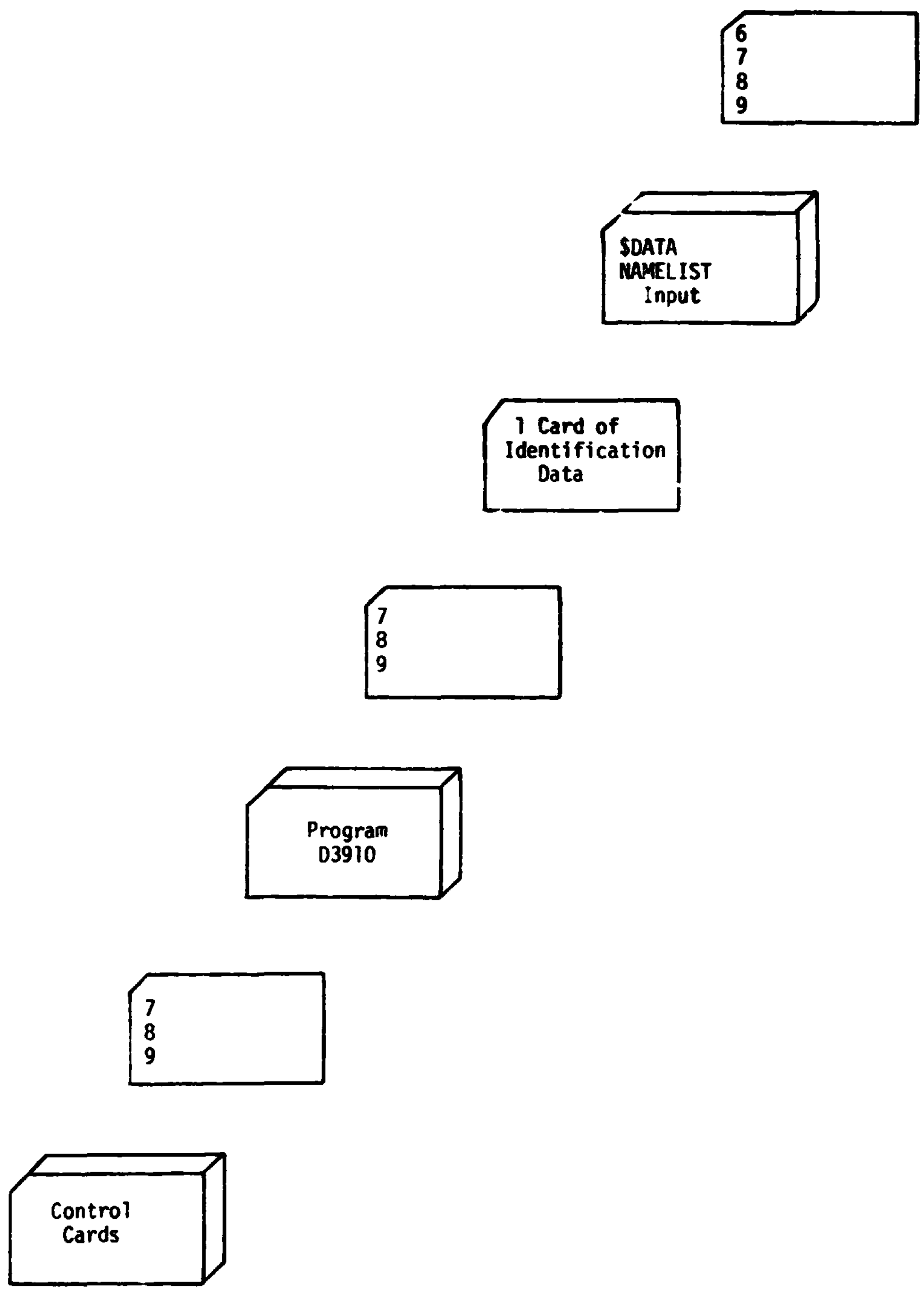
USAGE

Program Information

The program D3910 is run on the Control Data 6000 series under the SCOPE operating system. If the plot output is chosen, a 10" x 25" plot of the total sound pressure time history will be executed on the Varian plotting device. Minimum machine requirements are 55000_8 locations of core storage. The time required to compile the program is approximately 2.0 seconds. If the plot option is not activated, approximately .02 seconds are required to compute one time point of total sound pressure, and one O/S call is required for approximately 6 points. If the plot output is chosen, approximately 2 O/S calls are required for each point, and the time required for computing per point increases slightly.

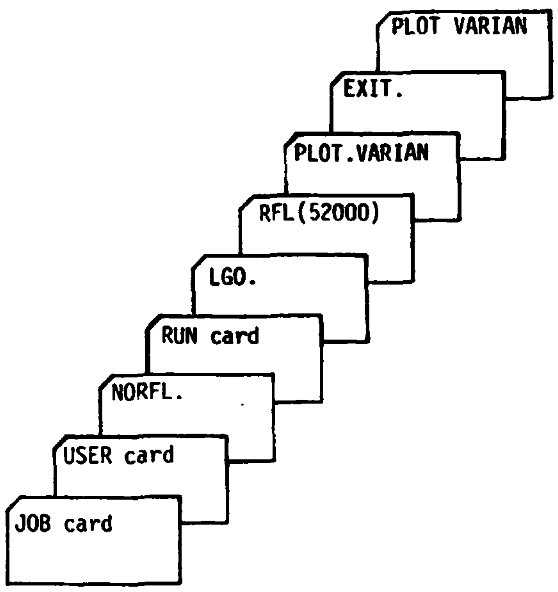
Deck Configuration

The following sketch shows the deck configuration needed for execution:

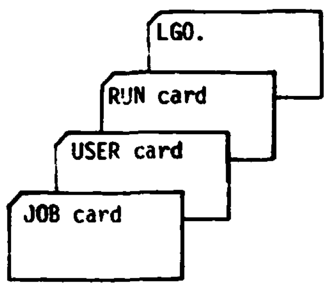


The following sketches show the control card configuration needed for execution both with and without plotting:

with plotting:



without plotting:



Input Description

The first card of input for each case is 80 columns of alphanumeric data which is printed out as an identification heading.

The succeeding cards of input use the FORTRAN NAMELIST capability with DATA as the NAMELIST name. The maximum allowable dimension appears following the variable name, unless it is a single value variable. Minimum and maximum allowable values and required units of the variable name are also given, if applicable.

ALPHA	the ratio of the magnitude of the torque force to the thrust force
RADIUS	the effective radius of the rotor disk inscribed by the net force on the blades, in meters
NBLADE	number of blades on the rotor, 1 ≤ NBLADE ≤ 4
PHI	angle made by the normal to the rotor disk and the horizontal direction, in degrees
RPM	velocity of the rotor, in revolutions/minute
VH	velocity of the vehicle, in meters/second
X(3)	initial position of the observer, in meters
N	number of harmonics of the load, 0 ≤ N ≤ 49
BETA	a constant used to determine the number of sets of total sound pressure to be computed (50 points per set); used only if VH = 0

NOTE: K = IFIX (BETA * XO/(VH*DELTAU*50)) + 1

where K = number of sets

XO = initial X(1) component

$$\text{DELTAU} = \frac{10}{\text{N*RPM*60}}$$

COEFF1(50) normalized amplitude of each harmonic obtained by the Fourier decomposition of the thrust; N+1 amplitudes must be supplied

COEFF2(50) phase angle of each harmonic obtained by the Fourier decomposition of the thrust; in degrees; N+1 phase angles must be supplied (set the phase angle of the fundamental to 0.0)

IPLOT plot option

IPLOT = 0; no plot

IPLOT $\neq$ 0; plot sound pressure vs. time

Output Description

The output of program D3910 consists of printing and optional plotting. For each case, the NAMELIST input is printed first. Then the alphanumeric identification input is printed, followed by a time history of total sound pressure. The time points that are printed are the times at which interpolation occurred. The total sound pressure that is printed is the sum of the interpolated values of sound pressure of all blades.

If IPLOT = 0, no plotting will occur. If IPLOT ≠ 0, a 10" x 25" Varian plot representing the time history of total sound pressure will be part of the output.

Input for Sample Case 1

```
   SAMPLE CASE 1 - VH = 15.
$DATA  ALPHA = .114, RADIUS = 4.3, NBLADE = 4, PHI = 26., RPM = 355.,
VH = 15., X = 30., 50., 10., N = 15, BETA = .25, IPLOT = 1,
COEFF1 = 1., .46238, .05370, .05012, .03273, .01905, .00891, .01585,
.02661, .00708, .00794, .00631, .01778, .00531, .00501, .00467, 34*0.,
COEFF2 = 0., 40., -25., 20., 15., -30., 44*0.$
```

Output for Sample Case 1

```
$DATA

ALPHA   =  0.114E+00,

BETA    =  0.25E+00,

COEFF1  =  0.1E+01,  0.46238E+00,  0.537E-01,  0.5012E-01,  0.3273E-01,
           0.1905E-01,  0.891E-02,  0.1585E-01,  0.2661E-01,  0.708E-02,
           0.794E-02,  0.631E-02,  0.1778E-01,  0.531E-02,  0.501E-02,
           0.467E-02,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,

COEFF2  =  0.0,  0.4E+02, -0.25E+02,  0.2E+02,  0.15E+02, -0.3E+02,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,

IPLOT   =  1,

N       =  15,

NBLADE  =  4,

PHI     =  0.26E+02,

RADIUS  =  0.43E+01,

RPM     =  0.355E+03,

VH      =  0.15E+02,

X       =  0.3E+02,  0.5E+02,  0.1E+02,

$END
```

SAMPLE CASE 1 - VH = 15.

TIME	INTERPOLATED PRESSURE SUM
1.6754662E-01	-1.1048203E-04
1.6785961E-01	-1.0056254E-04
1.6817260E-01	-9.3596051E-05
1.6848559E-01	-8.9755175E-05
1.6879858E-01	-8.9611816E-05
1.6911157E-01	-9.3547878E-05
1.6942456E-01	-1.0181726E-04
1.6973755E-01	-1.1456422E-04
1.7005054E-01	-1.3170905E-04
1.7036353E-01	-1.5299648E-04
1.7067651E-01	-1.7800772E-04
1.7098950E-01	-2.0602552E-04
1.7130249E-01	-2.3622509E-04
1.7161548E-01	-2.6768950E-04
1.7192847E-01	-2.9915038E-04
1.7224146E-01	-3.2944067E-04
1.7255445E-01	-3.5735942E-04
1.7286744E-01	-3.8148945E-04
1.7318043E-01	-4.0070023E-04
1.7349342E-01	-4.1395143E-04
1.7380640E-01	-4.2020154E-04
1.7411939E-01	-4.1880256E-04
1.7443238E-01	-4.0931672E-04
1.7474537E-01	-3.9158525E-04
1.7505836E-01	-3.6577129E-04
1.7537135E-01	-3.3229565E-04
1.7568434E-01	-2.9203063E-04
1.7599733E-01	-2.4598609E-04
1.7631032E-01	-1.9538694E-04
1.7662331E-01	-1.4189199E-04
1.7693630E-01	-8.6942965E-05
1.7724928E-01	-3.2394084E-05
1.7756227E-01	2.0154255E-05
1.7787526E-01	6.9214152E-05
1.7818825E-01	1.1321501E-04
1.7850124E-01	1.5105102E-04
1.7881423E-01	1.8182699E-04
1.7912722E-01	2.0488657E-04
1.7944021E-01	2.1999097E-04
1.7975320E-01	2.2725576E-04
1.8006619E-01	2.2709674E-04
1.8037917E-01	2.2018936E-04
1.8069216E-01	2.0763610E-04
1.8100515E-01	1.9049791E-04
1.8131814E-01	1.7027563E-04
1.8163113E-01	1.4829287E-04
1.8194412E-01	1.2587859E-04
1.8225711E-01	1.0449417E-04
1.8257010E-01	8.5210868E-05
1.8288309E-01	6.8672300E-05
1.8319608E-01	5.6675759E-05
1.8350907E-01	4.8624536E-05
1.8382205E-01	4.5062698E-05

1.8413504E-01	4.5903596E-05
1.8444803E-01	5.0777992E-05
1.8476102E-01	5.9137985E-05
1.8507401E-01	7.0289732E-05
1.8538700E-01	8.3290713E-05
1.8569999E-01	9.7313727E-05
1.8601298E-01	1.1133338E-04
1.8632597E-01	1.2451938E-04
1.8663896E-01	1.3611140E-04
1.8695194E-01	1.4539072E-04
1.8726493E-01	1.5191209E-04
1.8757792E-01	1.5534685E-04
1.8789091E-01	1.5557578E-04
1.8820390E-01	1.5263841E-04
1.8851689E-01	1.4677364E-04
1.8882988E-01	1.3828765E-04
1.8914287E-01	1.2769292E-04
1.8945586E-01	1.1546635E-04
1.8976885E-01	1.0212792E-04
1.9008184E-01	8.8284654E-05
1.9039482E-01	7.4392386E-05
1.9070781E-01	6.0897616E-05
1.9102080E-01	4.8161804E-05
1.9133379E-01	3.6410864E-05
1.9164678E-01	2.5799676E-05
1.9195977E-01	1.6354463E-05
1.9227276E-01	8.0320728E-06
1.9258575E-01	6.4389474E-07
1.9289874E-01	-5.9756963E-06
1.9321173E-01	-1.2071900E-05
1.9352471E-01	-1.7957180E-05
1.9383770E-01	-2.3877971E-05
1.9415069E-01	-3.0065778E-05
1.9446368E-01	-3.6770843E-05
1.9477667E-01	-4.4130226E-05
1.9508966E-01	-5.2235897E-05
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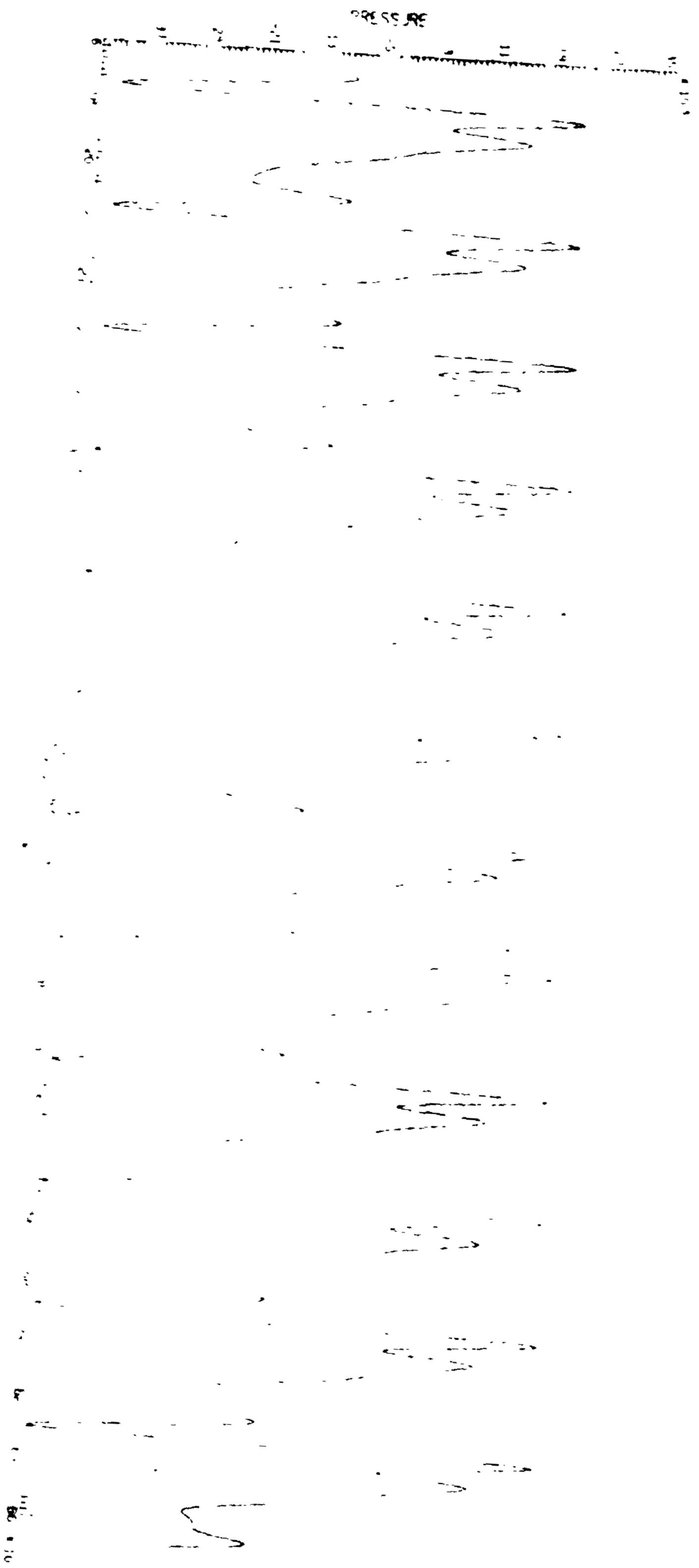
5.8350907E-01	-1.4044815E-04
5.8382205E-01	-1.5348992E-04
5.8413504E-01	-1.7070955E-04
5.8444803E-01	-1.9194031E-04
5.8476102E-01	-2.1674965E-04
5.8507401E-01	-2.4453113E-04
5.8538700E-01	-2.7451822E-04
5.8569999E-01	-3.0557432E-04
5.8601298E-01	-3.3663735E-04
5.8632597E-01	-3.6625025E-04
5.8663896E-01	-3.9308135E-04
5.8695194E-01	-4.1582703E-04
5.8726493E-01	-4.3299188E-04
5.8757792E-01	-4.4343317E-04
5.8789091E-01	-4.4615376E-04
5.8820390E-01	-4.4029346E-04
5.8851689E-01	-4.2543576E-04
5.8882988E-01	-4.0144540E-04
5.8914287E-01	-3.6858041E-04
5.8945586E-01	-3.2742253E-04
5.8976885E-01	-2.7906606E-04
5.9008184E-01	-2.2470959E-04
5.9039482E-01	-1.6615568E-04
5.9070781E-01	-1.0504352E-04
5.9102080E-01	-4.3553985E-05
5.9133379E-01	1.6432049E-05

5.9164678E-01	7.3003197E-05
5.9195977E-01	1.2420026E-04
5.9227276E-01	1.6860626E-04
5.9258575E-01	2.0486052E-04
5.9289874E-01	2.3219015E-04
5.9321173E-01	2.5011984E-04
5.9352471E-01	2.5865742E-04
5.9383770E-01	2.5828867E-04
5.9415069E-01	2.4979197E-04
5.9446368E-01	2.3447056E-04
5.9477667E-01	2.1374295E-04
5.9508966E-01	1.8919307E-04
5.9540265E-01	1.6272818E-04
5.9571564E-01	1.3593847E-04
5.9602863E-01	1.1060558E-04
5.9634162E-01	8.8037063E-05
5.9665461E-01	6.9510657E-05
5.9696759E-01	5.5808170E-05
5.9728058E-01	4.7475468E-05
5.9759357E-01	4.4612748E-05
5.9790656E-01	4.6985079E-05
5.9821955E-01	5.4120942E-05
5.9853254E-01	6.5145704E-05
5.9884553E-01	7.9157609E-05
5.9915852E-01	9.4946191E-05
5.9947151E-01	1.1145136E-04
5.9978450E-01	1.2746821E-04
6.0009748E-01	1.4201911E-04
6.0041047E-01	1.5426586E-04
6.0072346E-01	1.6350015E-04
6.0103645E-01	1.6932603E-04
6.0134944E-01	1.7153052E-04
6.0166243E-01	1.7014091E-04
6.0197542E-01	1.6542869E-04
6.0228841E-01	1.5776667E-04
6.0260140E-01	1.4774911E-04
6.0291439E-01	1.3594149E-04
6.0322738E-01	1.2305269E-04
6.0354036E-01	1.0971212E-04
6.0385335E-01	9.6467719E-05
6.0416634E-01	8.3844203E-05
6.0447933E-01	7.2173482E-05
6.0479232E-01	6.1714011E-05
6.0510531E-01	5.2546487E-05
6.0541830E-01	4.4648578E-05
6.0573129E-01	3.7835587E-05
6.0604428E-01	3.1898221E-05
6.0635727E-01	2.6473609E-05
6.0667025E-01	2.1229687E-05
6.0698324E-01	1.5807133E-05
6.0729623E-01	9.8165581E-06
6.0760922E-01	2.9990120E-06
6.0792221E-01	-4.9388577E-06
6.0823520E-01	-1.4140631E-05
6.0854819E-01	-2.4683465E-05
6.0886118E-01	-3.6578670E-05
6.0917417E-01	-4.9706638E-05
6.0948716E-01	-6.3911609E-05
6.0980015E-01	-7.8938033E-05
6.1011313E-01	-9.4515099E-05
6.1042612E-01	-1.1033063E-04
6.1073911E-01	-1.2601827E-04

6.1105210E-01	-1.4125982E-04
6.1136509E-01	-1.5576124E-04
6.1167808E-01	-1.6919183E-04
6.1199107E-01	-1.8134646E-04
6.1230406E-01	-1.9204813E-04
6.1261705E-01	-2.0115432E-04
6.1293004E-01	-2.0862081E-04
6.1324302E-01	-2.1443768E-04
6.1355601E-01	-2.1867397E-04
6.1386900E-01	-2.2143669E-04
6.1418199E-01	-2.2287313E-04
6.1449498E-01	-2.2320423E-04
6.1480797E-01	-2.2262623E-04
6.1512096E-01	-2.2138336E-04
6.1543395E-01	-2.1969391E-04
6.1574694E-01	-2.1778204E-04
6.1605993E-01	-2.1583806E-04
6.1637292E-01	-2.1405342E-04
6.1668590E-01	-2.1256063E-04
6.1699889E-01	-2.1143030E-04
6.1731188E-01	-2.1070763E-04
6.1762487E-01	-2.1038854E-04
6.1793786E-01	-2.1039663E-04
6.1825085E-01	-2.1064658E-04
6.1856384E-01	-2.1097248E-04
6.18[illegible]3E-01	-2.1120254E-04
6.19189[illegible]-01	-2.1114831E-04
6.1950281[illegible]01	-2.1057334E-04
6.1981579E-[illegible]1	-2.0928694E-04
6.2012878E-01	-2.0711453E-04
6.2044177E-01	-2.0391865E-04
6.2075476E-01	-1.9958165E-04
6.2106775E-01	-1.9409271E-04
6.2138074E-01	-1.8749919E-04
6.2169373E-01	-1.7993863E-04
6.2200672E-01	-1.7166374E-04
6.2231971E-01	-1.6298600E-04
6.2263270E-01	-1.5428046E-04
6.2294569E-01	-1.4609599E-04
6.2325867E-01	-1.3895347E-04
6.2357166E-01	-1.3339476E-04
6.2388465E-01	-1.3007973E-04
6.2419764E-01	-1.2955918E-04
6.2451063E-01	-1.3231413E-04
6.2482362E-01	-1.3876527E-04
6.2513661E-01	-1.4925201E-04
6.2544960E-01	-1.6388116E-04
6.2576259E-01	-1.8261703E-04
6.2607558E-01	-2.0517843E-04
6.2638856E-01	-2.3113664E-04
6.2670155E-01	-2.5972603E-04
6.2701454E-01	-2.9006313E-04
6.2732753E-01	-3.2112367E-04
6.2764052E-01	-3.5153172E-04
6.2795351E-01	-3.7999856E-04
6.2826650E-01	-4.0517747E-04
6.2857949E-01	-4.2552836E-04
6.2889248E-01	-4.3987322E-04
6.2920547E-01	-4.4693599E-04
6.2951846E-01	-4.4583002E-04
6.2983144E-01	-4.3590734E-04
6.3014443E-01	-4.1678894E-04

6.3045742E-01	-3.8850785E-04
6.3077041E-01	-3.5152679E-04
6.3108340E-01	-3.0662293E-04
6.3139639E-01	-2.5489837E-04
6.3170938E-01	-1.9796850E-04
6.3202237E-01	-1.3742582E-04
6.3233536E-01	-7.5397695E-05
6.3264835E-01	-1.3717169E-05
6.3296133E-01	4.5380462E-05
6.3327432E-01	1.0014670E-04
6.3358731E-01	1.4870000E-04
6.3390030E-01	1.8966243E-04
6.3421329E-01	2.2198152E-04
6.3452628E-01	2.4492040E-04
6.3483927E-01	2.5828605E-04
6.3515226E-01	2.6231836E-04
6.3546525E-01	2.5762126E-04
6.3577824E-01	2.4533490E-04
6.3609123E-01	2.2671447E-04
6.3640421E-01	2.0352057E-04
6.3671720E-01	1.7734288E-04
6.3703019E-01	1.5013004E-04
6.3734318E-01	1.2350056E-04
6.3765617E-01	9.9130732E-05
6.3796916E-01	7.8248949E-05
6.3828215E-01	6.1972416E-05
6.3859514E-01	5.0916739E-05
6.3890813E-01	4.5423257E-05
6.3922112E-01	4.5433018E-05
6.3953410E-01	5.0506458E-05
6.3984709E-01	5.9961998E-05
6.4016008E-01	7.2911694E-05
6.4047307E-01	8.8191307E-05
6.4078606E-01	1.0472295E-04
6.4109905E-01	1.2123813E-04
6.4141204E-01	1.3674131E-04
6.4172503E-01	1.5019912E-04
6.4203802E-01	1.6091584E-04
6.4235101E-01	1.6830615E-04
6.4266399E-01	1.7209715E-04
6.4297698E-01	1.7223523E-04
6.4328997E-01	1.6885935E-04
6.4360296E-01	1.6236931E-04
6.4391595E-01	1.5321311E-04
6.4422894E-01	1.4208327E-04
6.4454193E-01	1.2959483E-04
6.4485492E-01	1.1637797E-04
6.4516791E-01	1.0311400E-04
6.4548090E-01	9.0277577E-05
6.4579389E-01	7.8339985E-05
6.4610687E-01	6.7540660E-05
6.4641986E-01	5.8041303E-05
6.4673285E-01	4.9848537E-05
6.4704584E-01	4.2851754E-05
6.4735883E-01	3.6805265E-05
6.4767182E-01	3.1424054E-05
6.4798481E-01	2.6314965E-05
6.4829780E-01	2.1124895E-05
6.4861079E-01	1.5504877E-05
6.4892378E-01	9.0690819E-06
6.4923676E-01	1.5853547E-06
6.4954975E-01	-7.1771189E-06

6.4986274E-01	-1.7325391E-05
6.5017573E-01	-2.8866473E-05
6.5048872E-01	-4.1738810E-05
6.5080171E-01	-5.5806321E-05
6.5111470E-01	-7.0851710E-05
6.5142769E-01	-8.6577487E-05
6.5174068E-01	-1.0267890E-04
6.5205367E-01	-1.1882214E-04
6.5236666E-01	-1.3462703E-04
6.5267964E-01	-1.4980517E-04
6.5299263E-01	-1.6402077E-04
6.5330562E-01	-1.7702103E-04
6.5361861E-01	-1.8858402E-04
6.5393160E-01	-1.9856386E-04
6.5424459E-01	-2.0687233E-04
6.5455758E-01	-2.1347130E-04
6.5487057E-01	-2.1840255E-04
6.5518356E-01	-2.2174225E-04
6.5549655E-01	-2.2362008E-04
6.5580953E-01	-2.2424462E-04
6.5612252E-01	-2.2380811E-04
6.5643551E-01	-2.2253818E-04
6.5674850E-01	-2.2067598E-04
6.5706149E-01	-2.1845576E-04
6.5737448E-01	-2.1609773E-04
6.5768747E-01	-2.1380076E-04
6.5800046E-01	-2.1173160E-04
6.5831345E-01	-2.1001680E-04
6.5862644E-01	-2.0873450E-04
6.5893943E-01	-2.0793120E-04
6.5925241E-01	-2.0754997E-04
6.5956540E-01	-2.0754540E-04
6.5987839E-01	-2.0779134E-04
6.6019138E-01	-2.0814997E-04
6.6050437E-01	-2.0845409E-04
6.6081736E-01	-2.0844492E-04
6.6113035E-01	-2.0792984E-04
6.6144334E-01	-2.0672709E-04
6.6175633E-01	-2.0465762E-04
6.6206932E-01	-2.0156565E-04
6.6238230E-01	-1.9737293E-04
6.6269529E-01	-1.9206765E-04
6.6300828E-01	-1.8570662E-04
6.6332127E-01	-1.7845399E-04
6.6363426E-01	-1.7055860E-04
6.6394725E-01	-1.6232592E-04
6.6426024E-01	-1.5423435E-04
6.6457323E-01	-1.4675525E-04
6.6488622E-01	-1.4039634E-04
6.6519921E-01	-1.3581771E-04
6.6551220E-01	-1.3358208E-04
6.6582518E-01	-1.3419358E-04
6.6613817E-01	-1.3821522E-04
6.6645116E-01	-1.4600610E-04
6.6676415E-01	-1.5781888E-04
6.6707714E-01	-1.7374149E-04
6.6739013E-01	-1.9366090E-04
6.6770312E-01	-2.1729411E-04
6.6801611E-01	-2.4402262E-04


PRESSURE

Input for Sample Case 2

```
    SAMPLE CASE 2 - VH = 0.
 $DATA  ALPHA = .114, RADIUS = 4.3, NBLADE = 4, PHI = 26., RPM = 355.,
 VH = 0.0, X = 30., 50., 10., N = 15, BETA = .25, IPLOT = 1,
 COEFF1 = 1., .46238, .05370, .05012, .03273, .01905, .00891, .01585,
 .02661, .00708, .00794, .00631, .01778, .00531, .00501, .00467, 34*0.,
 COEFF2 = 0., 40., -25., 20., 15., -30., 44*0.$
```

Output for Sample Case 2

```
$DATA

ALPHA   =  0.114E+00,

BETA    =  0.25E+00,

COEFF1  =  0.1E+01,  0.46238E+00,  0.537E-01,  0.5012E-01,  0.3273E-01,
           0.1905E-01,  0.891E-02,  0.1585E-01,  0.2661E-01,  0.708E-02,
           0.794E-02,  0.631E-02,  0.1778E-01,  0.531E-02,  0.501E-02,
           0.467E-02,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,

COEFF2  =  0.0,  0.4E+02,  -0.25E+02,  0.2E+02,  0.15E+02,  -0.3E+02,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,
           0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,  0.0,

IPLOT   =  1,

N       =  15,

NBLADE  =  4,

PHI     =  0.26E+02,

RADIUS  =  0.43E+01,

RPM     =  0.355E+03,

VH      =  0.0,

X       =  0.3E+02,  0.5E+02,  0.1E+02,

$END
```

SAMPLE CASE 2 - VH = 0.

TIME	INTERPOLATED PRESSURE SUM
1.6754662E-01	-9.8168699E-05
1.6785961E-01	-8.9946559E-05
1.6817260E-01	-8.4794174E-05
1.6848559E-01	-8.2803857E-05
1.6879858E-01	-8.4442589E-05
1.6911157E-01	-8.9974628E-05
1.6942456E-01	-9.9560232E-05
1.6973755E-01	-1.1322948E-04
1.7005054E-01	-1.3082011E-04
1.7036353E-01	-1.5200040E-04
1.7067651E-01	-1.7629254E-04
1.7098950E-01	-2.0309027E-04
1.7130249E-01	-2.3148700E-04
1.7161548E-01	-2.6060374E-04
1.7192847E-01	-2.8947183E-04
1.7224146E-01	-3.1687079E-04
1.7255445E-01	-3.4172781E-04
1.7286744E-01	-3.6295606E-04
1.7318043E-01	-3.7958169E-04
1.7349342E-01	-3.9057819E-04
1.7380640E-01	-3.9524344E-04
1.7411939E-01	-3.9302453E-04
1.7443238E-01	-3.8354870E-04
1.7474537E-01	-3.6675843E-04
1.7505836E-01	-3.4278021E-04
1.7537135E-01	-3.1213166E-04
1.7568434E-01	-2.7548103E-04
1.7599733E-01	-2.3367528E-04
1.7631032E-01	-1.8798304E-04
1.7662331E-01	-1.3963477E-04
1.7693630E-01	-8.9926207E-05
1.7724928E-01	-4.0462178E-05
1.7756227E-01	7.3935923E-06
1.7787526E-01	5.2359301E-05
1.7818825E-01	9.3073838E-05
1.7850124E-01	1.2853553E-04
1.7881423E-01	1.5795272E-04
1.7912722E-01	1.8070387E-04
1.7944021E-01	1.9653037E-04
1.7975320E-01	2.0540410E-04
1.8006619E-01	2.0764493E-04
1.8037917E-01	2.0377306E-04
1.8069216E-01	1.9450262E-04
1.8100515E-01	1.8090751E-04
1.8131814E-01	1.6402056E-04
1.8163113E-01	1.4494623E-04
1.8194412E-01	1.2500651E-04
1.8225711E-01	1.0530095E-04

1.8257010E-01	8.6864698E-05
1.8288309E-01	7.0198226E-05
1.8319608E-01	5.7380940E-05
1.8350907E-01	4.7629658E-05
1.8382205E-01	4.1684601E-05
1.8413504E-01	3.9631542E-05
1.8444803E-01	4.1313829E-05
1.8476102E-01	4.6396805E-05
1.8507401E-01	5.4410148E-05
1.8538700E-01	6.4641043E-05
1.8569999E-01	7.6389519E-05
1.8601298E-01	8.8922410E-05
1.8632597E-01	1.0135807E-04
1.8663896E-01	1.1301525E-04
1.8695194E-01	1.2325615E-04
1.8726493E-01	1.3146824E-04
1.8757792E-01	1.3727899E-04
1.8789091E-01	1.4039438E-04
1.8820390E-01	1.4070029E-04
1.8851689E-01	1.3820919E-04
1.8882988E-01	1.3310286E-04
1.8914287E-01	1.2563874E-04
1.8945586E-01	1.1617198E-04
1.8976885E-01	1.0516209E-04
1.9008184E-01	9.3049664E-05
1.9039482E-01	8.0267064E-05
1.9070781E-01	6.7312425E-05
1.9102080E-01	5.4561512E-05
1.9133379E-01	4.2313684E-05
1.9164678E-01	3.0855206E-05
1.9195977E-01	2.0354296E-05
1.9227276E-01	1.0890558E-05
1.9258575E-01	2.4650386E-06
1.9289874E-01	-5.0075716E-06
1.9321173E-01	-1.1653636E-05
1.9352471E-01	-1.7636003E-05
1.9383770E-01	-2.3201474E-05
1.9415069E-01	-2.8550253E-05
1.9446368E-01	-3.3889169E-05
1.9477667E-01	-3.9453786E-05
1.9508966E-01	-4.5392390E-05
1.9540265E-01	-5.1829488E-05
1.9571564E-01	-5.8843777E-05
1.9602863E-01	-6.6474597E-05
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1.9665461E-01	-8.3443642E-05
1.9696759E-01	-9.2628560E-05
1.9728058E-01	-1.0211453E-04
1.9759357E-01	-1.1174296E-04
1.9790656E-01	-1.2137448E-04
1.9821955E-01	-1.3082049E-04
1.9853254E-01	-1.3996269E-04
1.9884553E-01	-1.4867197E-04
1.9915852E-01	-1.5685992E-04
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1.9978450E-01	-1.7135340E-04
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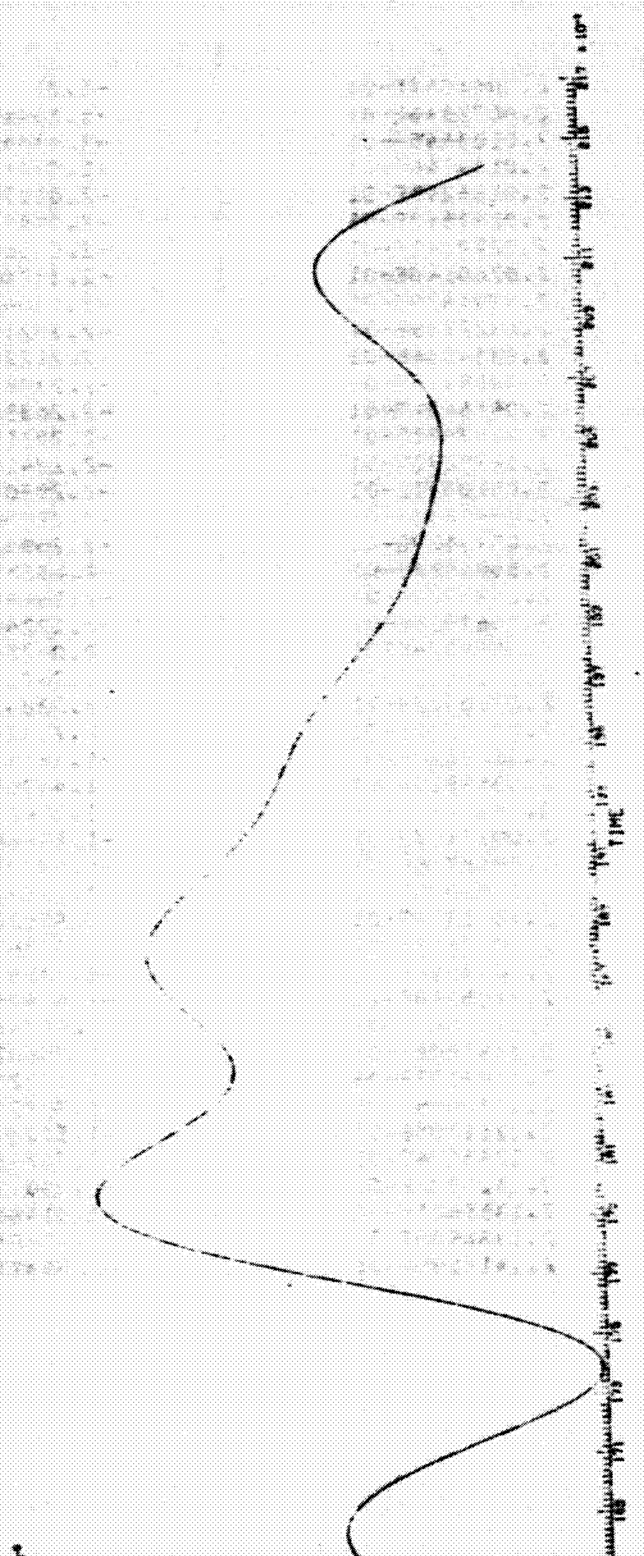
2.0197542E-01	-2.0485689E-04
2.0228841E-01	-2.0836513E-04
2.0260140E-01	-2.1175053E-04
2.0291439E-01	-2.1504458E-04
2.0322738E-01	-2.1821923E-04
2.0354036E-01	-2.2122703E-04
2.0385335E-01	-2.2398429E-04
2.0416634E-01	-2.2635843E-04
2.0447933E-01	-2.2821968E-04
2.0479232E-01	-2.2941030E-04
2.0510531E-01	-2.2970736E-04
2.0541830E-01	-2.2895061E-04
2.0573129E-01	-2.2695246E-04
2.0604428E-01	-2.2355769E-04
2.0635727E-01	-2.1868676E-04
2.0667025E-01	-2.1224131E-04
2.0698324E-01	-2.0422880E-04
2.0729623E-01	-1.9471913E-04
2.0760922E-01	-1.8384778E-04
2.0792221E-01	-1.7182454E-04
2.0823520E-01	-1.5898798E-04
2.0854819E-01	-1.4570063E-04
2.0886118E-01	-1.3242792E-04
2.0917417E-01	-1.1966443E-04
2.0948716E-01	-1.0792337E-04
2.0980015E-01	-9.7844274E-05
2.1011313E-01	-8.9963098E-05
2.1042612E-01	-8.4794175E-05
2.1073911E-01	-8.2803857E-05
2.1105210E-01	-8.4442589E-05
2.1136509E-01	-8.9974627E-05
2.1167808E-01	-9.9560230E-05
2.1199107E-01	-1.1322948E-04
2.1230406E-01	-1.3082011E-04
2.1261705E-01	-1.5200040E-04
2.1293004E-01	-1.7629254E-04
2.1324302E-01	-2.0309026E-04
2.1355601E-01	-2.3148699E-04
2.1386900E-01	-2.6060374E-04
2.1418199E-01	-2.8947182E-04


PRESSURE
TIME

Error Diagnostics

The following table gives the error diagnostics as the message and the reason for getting the message. All of the errors are fatal.

Message	Reason
TIME HAS NOT REACHED TMIN FOR BLADE I	The ith blade has been rotated back 1000 time increments, but its initial arrival time has not yet reached a close enough range to TMIN.
MACH NUMBER IS NOT LESS THAN ONE. PROGRAM ABORTED.	This analysis is to be applied only to velocities less than Mach 1.
BLADE I FAILED TO REACH TMAX IN 200 ITERATIONS FOR INTERPOLATION SET K.	The ith blade has not reached TMAX after 200 points have been computed starting from its respective initial time; occurred during interpolation set k.
ITH ELEMENT OUT OF ORDER. NO INTERPOLATION. IORDER = 0 ONE ELEMENT IN X ARRAY INSUFFICIENT NUMBER OF POINTS. NO INTERPOLATION.	Error messages from IUNI

APPENDIX

SUBROUTINE IUNI

LANGUAGE: FORTRAN

PURPOSE: To interpolate a univariate function using conventional first or second order Lagrangian interpolation. The routine will perform multiple table look-up for a set of functions defined over the same set of independent parameter points. The points in the independent parameter array can be unequally spaced.

USE: CALL IUNI (NMAX,N,X,NTAB,Y,IORDER,XO,YO,IPT,IERR)

NMAX	An input integer specifying the maximum first dimension of the functional value array as given in the dimension statement of the calling program.
N	An input integer specifying the actual number of independent parameter points, where N $\leq$ NMAX.
X	An input array dimensioned at least N in the calling program. This array contains the values of the independent parameter. The elements of the X array must be strictly monotonic.
NTAB	An input integer specifying the number of dependent variable tables.
Y	A two-dimensional input array whose columns contain the dependent variable

tables. The Y array should have first dimension NMAX and second dimension at least NTAB.

IORDER — An input integer specifying the order of interpolation to be used

= 0 Zero order interpolation: The first value in the dependent variable table is assigned as the interpolated value of the function.

= 1 First order interpolation.

= 2 Second order interpolation.

XO — The point at which interpolation is to be performed.

YO — An output array containing the interpolated value of each function. This array should be dimensioned NTAB in the calling program.

IPT — An input/output integer parameter with the following functions

INPUT: Initialize routine IUNI and check monotonicity of the X array.

= -1 Whenever a new X array is input, this value of IPT must be specified by the user so that a monotonicity check of the X array will be performed.

OUTPUT: INDEX POINTER

= k Indicates that $x_k \le x_0 < x_{k+1}$. On the next call, the previous value of IPT is used as a pointer to begin the search for the subinterval containing the next interpolation point.

Whenever the point x_0 is not contained in the interval delimited by the X array, extrapolation is performed to estimate the function value. In this case the value of IPT is returned as:

= 0 Indicates $x_0 < x(1)$ if the X array is in increasing order, or $x_0 > x(1)$ if the X array is arranged in decreasing order.

= N Indicates $x_0 > x(N)$ if the X array is in increasing order, or $x_0 < x(N)$ is the X array is arranged in decreasing order.

IERR Integer error parameter generated by the routine.

= 0 Normal return

= J The J-th element of the X array was out of order. No interpolation performed.

IUNI

= -1 Zero order interpolation performed because IORDER = 0.

= -2 Zero order interpolation performed because only one point was in the X array.

= -3 Insufficient number of points supplied for second order interpolation. No interpolation performed.

= -4 Extrapolation was performed.

The parameter IERR should be tested upon return to the calling program.

RESTRICTIONS: The points in the X array must be arranged in strictly increasing or decreasing order of magnitude.

Whenever a new X array is provided, the parameter IPT = -1 must be input by the user to insure the routine will be properly initialized and the monotonicity of the X array checked.

METHOD: In table look-up for scientific computing, consecutive interpolation points tend to fall in the same region of the independent variable table. The parameter IPT provides an index to begin the search for the subinterval containing XO. IPT is used to initialize the routine on the first call; thereafter it preserves the location in the table of the previous answer. This feature was implemented to minimize the amount of search time.

IUNI

If $Y_1, Y_2, \ldots, Y_N$ are the values of the function evaluated at the tabulated values $X_1, X_2, \ldots, X_N$ of the independent variable, then the interpolation equations are as follows:

Second Order: The index i is chosen so that

$$\left| x_0 - x_i \right| + \left| x_0 - x_{i+2} \right| \text{ is a minimum}$$

$$Y_0 = \frac{1}{(x_{i+2} - x_i)} \left[\frac{(y_i(x_{i+1} - x_0) - y_{i+1}(x_i - x_0))(x_{i+2} - x_0)}{(x_{i+1} - x_i)} - \frac{(y_{i+1}(x_{i+2} - x_0) - y_{i+2}(x_{i+1} - x_0))(x_i - x_0)}{(x_{i+2} - x_{i+1})} \right]$$

First Order: For $x_i \leq x_0 \leq x_{i+1}$

$$Y_0 = y_i + \frac{(y_{i+1} - y_i)(x_0 - x_i)}{(x_{i+1} - x_i)}$$

ACCURACY: Accuracy is a function of the order of interpolation used.

REFERENCES: Nielson, K. L., Methods in Numerical Analysis; pp. 87-91.
Ralston, A., A First Course in Numerical Analy is; pp. 42-46

STORAGE: 404 octal locations

SUBPROGRAMS USED: None

FORTRAN FUNCTIONS: SIGN

SUBROUTINE PSEUDO

LANGUAGE: COMPASS

PURPOSE: To create and write an appropriately named Plot Vector File. Through linkages set up by an initial call to PSEUDO, all subsequent graphics data generated by the user will be routed through one of the PSEUDO entry points and written on the Plot Vector File.

USE:

```
CALL PSEUDO
    or
CALL PSEUDO (FN)
```

FN file name left-justified with zero fill. Default file name is SAVPLT.

Example:

```
CALL PSEUDO
```

This will establish a Plot Vector File named SAVPLT.

```
CALL PSEUDO (6LMYFILE)
```

This will establish a Plot Vector File named MYFILE.

NOTE: The Plot Vector File (or Files) will usually be written to disk (as opposed to tape) and may be postprocessed following user program termination via appropriate specification of one or more PLOT control cards.

PSEUDO

RESTRICTIONS: (1) An initializing call to PSEUDO (with or without a file name argument) must be made prior to any calls to CALPLT or any other graphics output routine.

(2) Every Plot Vector File should be terminated with a 999 pen code, CALL CALPLT (0.0,0.0,999). The transmission of the 999 code will cause an EOF write on the Plot Vector File, and the file will temporarily be closed. Thus, any given Plot Vector File will contain only one 999 pen code and/or one EOF.

(3) To continue plotting execution following transmission of a 999 code to a current Plot Vector File, the user program must call the PSEUDO processor to create new Plot Vector File (i.e., CALL PSEUDO (6LMYFIL2)).

METHOD: In addition to entry PSEUDO, this processor contains two other entry points, namely PLT9999 and PLT9998. An initializing call to PSEUDO will set PLT9999 into the processor switching mechanism (PLOTSW). Subsequent plot data generation will then be routed via CALPLT, PLOTSW, and PLT9999 and written on the Plot Vector File. The entry PLT9998 is used to record special purpose data from routines NFRAME and PLTSTOP.

STORAGE: 2155_8 locations total for direct subprograms

SUBPROGRAMS USED: NUMARG, PLOTSW

SUBROUTINE CALPLT

LANGUAGE: FORTRAN

PURPOSE: To move the plotter pen to a new location with pen up or down.

USE: CALL CALPLT(X,Y,IPEN)

where

X,Y	are the floating point values for pen movement.
IPEN = 2	pen down
= 3	pen up
	Negative IPEN will assign X = 0, Y = 0 as the location of the pen after moving the X,Y (create a new reference point).
= 999	Writes a terminating block address of 999 to terminate the Plot Vector File and all further processing is skipped.

CALL CALPLT(0.0,0.0,999)

RESTRICTIONS: All X and Y coordinates must be expressed as floating point inches (actual page dimensions) in deflection from the origin.

A TERMINATING BLOCK ADDRESS (IPEN = 999) MUST BE GIVEN AS THE LAST PLOTTING INSTRUCTION BEFORE ENDING A PROGRAM WHICH USES ANY OF THE PLOTTER SUBROUTINES. THIS IS TO BE SURE THAT ALL PLOTTER INSTRUCTIONS ARE WRITTEN ON THE PLOTTER TAPE.

CALPLT

METHOD: The main subroutine in the graphics language is the CALPLT subroutine. All other special purpose subroutines eventually call CALPLT either directly or indirectly. This routine moves the pen in a straight line between the present pen position and another pen location to which the programer wishes the pen to be moved.

In order to cause such instructions to be written, the programer specifies the coordinates of the point to which the pen is to be moved and whether the pen is to be moved in a raised or lowered position. This is accomplished by the FORTRAN instruction:

```
CALL CALPLT(X,Y,IPEN)
```

A new plot origin within a frame is created by a call to CALPLT with the argument, IPEN, negative. The CALPLT routine then moves the pen to X,Y; stores this location as (0,0), that is, a new origin. Each call to CALPLT with IPEN negative will establish a new plot origin within frame. After a frame of plotting is completed, a call to NFRAME should be used to establish a new frame origin. This new frame origin is referred from the last frame origin, not from the last plot origin created by a call to CALPLT with the argument, IPEN, negative.

STORAGE: 251_8 locations 6000 series

SUBPROGRAMS USED: PLOTSW, STRCALL, LOCATE

SUBROUTINE AXES

LANGUAGE: FORTRAN

PURPOSE: To draw a line, annotate the value of the variable at specified intervals with or without tic marks, and provide an axis identification label.

USE:

```
CALL AXES(X,Y,THETA,S,ORG,SFX,TMAJ,TMIN,BCD,HEIGHT,NOCHAR)
```

where

X,Y	are the coordinates in floating point inches of the starting point of the axis with reference to the plotting area origin as established by CALPLT.
THETA	is the angle of rotation measured counter-clockwise from the X-axis in floating point degrees. Normally, THETA is 0° for an X-axis and 90° for a Y-axis.
S	is the length of the axis in floating point inches. Should be a multiple of TMAJ. +S will generate tic marks. -S will eliminate tic marks.
ORG	is the functional value to be assigned to the origin (i.e., the value of the first scale) in floating point.

SFX	is the adjusted scale factor for the array to be plotted (change in value per inch). **NOTE:** Values of ORG and SFX which will produce a reasonable scale may be calculated using the subroutine ASCALE or BSCALE.
TMAJ	is the distance in floating point inches for major tic marks (0.25 inches high). Numbers are placed on the axis at the major tic marks in accordance with the values of ORG and SFX. The numbers written along the axis are adjusted to be between 1000.00 and 0.01 in magnitude. Immediately after the last number on the axis is placed the caption $x10^{exp}$, where exp is the required exponent. If the values are integer multiples, the decimal point and decimal places are eliminated. A negative TMAJ will cause the actual value to be written instead of the adjusted value.
TMIN	is the number of divisions per inch in floating point for minor tic marks (0.125 inches high). To eliminate minor tic marks the following may be used: TMIN = 0.

BCD	is the character label for the axis (see NOTATE routine).
HEIGHT	is the height of the full-size characters in the BCD title. Numbers at the tic marks will be (0.75*HEIGHT) high. HEIGHT is in floating point inches. If HEIGHT = 0., all annotation will be eliminated.
NOCHAR	is an integer specifying the number of characters in BCD title. A negative NOCHAR places the annotation on the clockwise side of the axis and a positive NOCHAR places the annotation on the counterclockwise side of the axis. NOCHAR = 0 is not allowed. If it is desired to have no label, then the BCD parameter should be 1H , and NOCHAR either +1 or -1.

RESTRICTIONS: Only perpendicular axes are recommended.

STORAGE: 1451_8 locations 6000 series

SUBPROGRAMS USED: CALPLT, NOTATE, NUMBER, ROUND, SIN, COS, WHERE

SUBROUTINE LINE

LANGUAGE: FORTRAN

PURPOSE: To draw a continuous line through and/or draw a symbol at each successive data point (stored in an array).

USE: CALL LINE(XARRAY,YARRAY,N,K,J,L,HEIGHT)

where

XARRAY, YARRAY — are the names of arrays containing the X values and Y values, respectively, to be plotted. Values must be in floating point.

N — is the number of points to be plotted.

K — is the interleave factor which specifies the sequence in which data are stored.

= 1 indicates that values are stored sequentially.

= 2 indicates that values are stored in every other location in the array, etc.

J — is positive for line and symbol plot, negative for symbol only plot. The magnitude specifies the alternate number of data points at which to plot a symbol.

	= 0 for line plot.
	= 1 for symbol for every data point.
	= 2 for symbol for every other data point, etc.
L	is an integer describing symbol to be used; see NOTATE routine for list.
HEIGHT	is the desired symbol height in floating point (see NOTATE routine).

RESTRICTIONS: LINE expects the adjusted minimums and scale factors as described in ASCALE.

STORAGE: 352_8 locations 6000 series

SUBPROGRAMS USED: CALPLT, NOTATE, WHERE

SUBROUTINE NFRAME

LANGUAGE: FORTRAN

PURPOSE: To provide users specific means of executing frame advance movements on any plotter device via an appropriate frame oriented device postprocessor. Frame advance distances are generally defined to be incremental from current frame origin (i.e., comparable to frame advance executions for the DDI or 252 CRT devices). CALL NFRAME is intended to be used as a frame advance mechanism, not as a plot origin offset.

USE:

```
CALL NFRAME
     or
CALL NFRAME(H,V)
```

where

H and V	are Horizontal (parallel to device X) and Vertical (parallel to device Y) distances from the current frame origin. H and/or V must be expressed in floating point inches.

The short form CALL NFRAME will cause the device postprocessor to execute a frame advance move parallel to the device X (horizontal) axis. The movement will be the maximum horizontal distance used in inches plus h inches, where h will be an increment appropriate to the particular device ($0 < h \leq 2''$). The frame advance will be rounded to whole inches.

When H and V parameters are provided on the NFRAME call, only the following values are permissible:

CALL NFRAME(H,0.) Frame advance H" horizontal
CALL NFRAME(0.,V) Frame advance V" vertical
CALL NFRAME(H,V) Frame advance H" by V"
CALL NFRAME(0.,0.) Return to current frame origin
CALL NFRAME(H,-V) Frame advance H" by -V"

This should be used to execute a frame advance move parallel to horizontal axis and establish a new origin for roll paper plotters and return to origin for flatted plotters.

RESTRICTIONS:

1. This routine is intended for use only in concert with the frame-dependent graphics postprocessors.

2. This routine must be used in any case which may require AUTO modification of Plot Vector File data by a graphics postprocessor.

3. The frame advance distances specified by H and/or V should always be at least slightly greater than the intended usable frame size. H and V are ignored by the Varian and DDI postprocessors.

4. The H dimensions of a frame advance may not be negative ($H \geq 0$). For purposes of frame stacking, V may be either negative, zero, or positive.

STORAGE: 76_8 memory words, CDC 6000 series

SUBPROGRAMS USED: NUMARG, CALPLT, PLT9998, ABORT

REFERENCES

1. M. V. Lowson (1965), Proceedings of the Royal Society of London, Series A, Vol. 286, pp 559 - 572; The Sound Field for Singularities in Motion.

2. F. Farassat (1974), Proceedings of the Interagency Symposium on University Research in Transportation Noise, Vol. 1, pp 363 - 370; Some Research on Helicopter Rotor Noise - Thickness and Rotational Noise.